New Hampshire
Bio-oil Assessment Analysis

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1. Executive Summary

The study reported herein is part of a continuing effort to determine the feasibility of utilizing low-grade wood to establish a bio-oil (pyrolysis liquid) industry and market in New Hampshire. An earlier study supported by the New Hampshire Office of Energy and Planning (OEP) was designed to assess the feasibility of bio-oil production in New Hampshire. The earlier study provided a conceptual commercialization plan but did not address specifics as to potential partners, location, and market analysis. This second study, also funded by (OEP), is intended to identify specific businesses capable of establishing an economically viable bio-oil industry in New Hampshire, evaluate the market potential for the resulting products, determine the most likely location for such an industry, and initiate relationships among project developers, state officials, community leaders, and potential sources of financial support. It is understood that this study can only plant the seed (i.e. introduce the interested parties), whose germination and growth depends upon the participants and events that may or may not occur in the near term. This study was performed with the understanding that a sustained market for low-grade wood can support quality forest management, create jobs and stimulate growth in the largely rural, forest-based sector of New Hampshire's economy.

This study substantiates the findings of the earlier study in that the work indicates neither a stand-alone bio-oil facility producing only bio-oil and char as products nor a stand-alone electric power generation plant utilizing bio-oil as its fuel would be economically viable without government support. Subsidies on the order of 59 ¢/gal for bio-oil and 2 to 4 ¢/kWh in addition to the plants ability to sell RPS credits would be required to assure economic stability. Even with a subsidy, it is questionable as to whether a market for bio-oil could be established without government-supported use by industry and/or institutional facilities. One hurdle is the lack of incentives in New Hampshire. Other states may be more attractive as potential locations for stand-alone or co-located production and marketing of bio-oil. The home heating oil market is not a potential market for the foreseeable future.

It has been widely believed that as the price of crude oil increased, the economics of bio-oil and/or other biomass applications using low-grade wood as a feedstock would improve. Current market conditions show that this is not the case. The cost of green wood chips in northern New Hampshire have risen linearly with the increase in crude oil, thus showing no economic advantage for bio-oil. This is largely the result of the fuel-intensive processes of chipping and hauling.

A stand-alone bio-refinery could, in theory, produce higher value added chemicals in addition to bio-oil and/or electric power. This would make the facility potentially more economically viable. However, a bio-refinery would be vulnerable to the availability and price of low-grade wood chips and would have the difficult and costly task of developing a sustainable market for its products. Investors tend to avoid projects that do not have a developed market as well as those with high initial capital cost such as a bio-refinery. A more likely scenario would be the association of a bio-refinery with an existing wood products plant such as a sawmill, kiln, fiberboard mill, OSB plant or veneer mill. A co-located facility would benefit from a stable supply of low-cost feedstock in the form of process residue while having a captive consumer of the products; bio-oil, electric power, and/or specific value added chemicals. Thus, the bio-refinery eliminates the need to develop a market while identifying a potential primary investor. This is the configuration currently being used by all bio-oil facilities in North America.

Unfortunately this operating structure is not applicable to New Hampshire. In reviewing currently operating forest products plants in the state, it was found that there are no plants large enough to support such a facility, either by producing adequate feedstock and/or utilizing a significant portion of the electric power, process heat or chemicals that would be produced. It is deemed unlikely that the state would be able to attract such forest product plants in the foreseeable future.

An alternative approach in New Hampshire would be to co-locate a bio-refinery with an existing wood-fired power plant. Although co-location with an existing wood fired power plant would be economically attractive, it is less attractive than co-location with a wood products plant in that the power plant would not be a source of low-cost feedstock and would not be a consumer of chemical products. Consequently, the suppliers of bio-refinery technology are focusing their available resources on developing business partnerships with forest products plants. Since appropriate forest products plants are not available in New Hampshire there is less reason for a bio-refinery to consider locating in New Hampshire without suitable incentives. Such incentives could include financial support by local and state government to reduce the cost of money for capital equipment and construction costs. Such support is currently available from several southeastern states, which have ample supplies of feedstock and active forest products industries. Without similar support, it is unlikely that New Hampshire will be able to attract a bio-refinery.

This study introduced the supplier of bio-refinery technology in North America to an interested owner of a wood-fired power plant located in northern New Hampshire. Potential investors, both private and institutional, who would be interested in evaluating a business plan, have also been identified. Although the interested parties continue their discussions, it is unlikely that any progress will be forthcoming in the foreseeable future unless state and local government offer subsidies or tax incentives.

2. Introduction

2.1 Bio-oil for New Hampshire: Historical Overview

In 2001 several groups in northern New Hampshire began looking at a new technology, fast pyrolysis, as a possible alternative market for wood chips. Fast pyrolysis is a process whereby biomass, such as wood, is converted into a liquid referred to as bio-oil. Hence the process has become known by the common name "bio-oil". A study of bio-oil was initiated because of the closing of three of the state's wood-fired power plants and the potential closing of the remaining five plants when their rate orders expire in 2007-8. Closing of three wood-fired power plants resulted in an approximately 30% decrease in demand for whole-tree chips, the major fuel for the power plants. A strong market for wood chips is important because it provides both an income for loggers and an economic incentive for landowners to improve the quality of their forests and woodlots through better forest management.

At the same time the wood-fired power plants were closing, the area was also experiencing a slowdown in the paper industry with the closing of several paper and pulp mills, which resulted in a further decrease in demand for wood chips. Overall, this resulted in an economic downturn for the North Country with the loss of jobs and declining tax revenue.

The bio-oil initiative was started by the Business and Economic Development Corporation (BEDCO) an economic development group representing the three northern-most counties in New Hampshire; Grafton, Coös and Carroll. In October 2001, a meeting on bio-oil was held at the State House in Concord. In attendance were economic development groups representing various regions of the state, universities, private groups and representatives from several state and local government agencies. DynaMotive Energy Systems Corporation, an early leader in the development of the bio-oil technology, was invited to speak on the subject. After this meeting, the New Hampshire Office of Energy and Planning (OEP),[1] along with support from the Department of Resources and Economic Development (DRED), became the lead group for further evaluation of bio-oil technology for New Hampshire.

In 2002 OEP received a U.S. Department of Energy grant to study the economic, environmental and technical feasibility of establishing a bio-oil production and utilization industry in New Hampshire. The study team included US and Canadian federal agencies; agencies of several states; universities; forest industry, environmental, and biomass energy organizations; economic development organizations; and private individuals. The final report was published in September, 2004.[2]

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[1] Formerly known as the Governor's Office of Energy and Community Services (ECS)
[2] New Hampshire Office of Energy and Planning. *New Hampshire Bio-oil Opportunity Analysis*. September, 2004. available at http://nh.gov/oep/programs/energy/bioOil.htm

The final project report, "Bio-oil Opportunity Analysis", includes: evaluation of pyrolysis technologies; chemical and physical characterization of bio-oil; availability of feedstock on a sustainable basis; environmental factors from forest ecology through end-uses; market analysis and attractiveness to potential investors. The report includes a Bio-oil Commercialization Plan and the economic model spreadsheet used in the Plan.

The "Bio-oil Commercialization Plan"[3] presented two economically viable scenarios for locating a bio-oil plant in New Hampshire: 1.) Co-locate a bio-oil facility with an existing wood fired-power plant such that utilization of waste heat from the power plant could be used to dry the feedstock, with cost sharing of facilities and labor to reduce the operating and capital costs or 2.) Operate a bio-refinery where higher value added products such as phenolic resigns would be extracted and sold in addition to selling the residual bio-oil for heating and/or electric power generation. Other options, such as a stand-alone bio-oil facility or an electric power generating plant utilizing bio-oil as a fuel did not appear to be economically viable at the time.

2.2 Benefits of Bio-oil

The consumption of fossil fuels continues to increase both in New Hampshire and nationwide. In the year 2000, 59% of New Hampshire's primary energy consumption was from fossil fuels.[4] This is expected to increase to 69% by the year 2020. Since bio-oil is produced from renewable resources with significantly lower emissions than coal, and petroleum oil, it provides many potential advantages over these conventional fossil fuels.

In the 1980's biomass electric power plants were established in New Hampshire in an effort to create energy diversification and a new market for "low-grade" wood products. By 1990, eight privately-owned biomass electric power plants were operating in NH producing approximately 6% of the states electric power and consuming 1.2 million tons of whole-tree chips per year. In 2000 the amount of electricity generated from biomass had dropped to 3.8%; the result of three biomass plant closings.[5] Biomass power faces challenges with the expiration of rate orders, lower energy-efficient power generation and the ability to manage and transport fuel sources. Current rate orders begin to expire in 2007 with no chance for renewal. With the estimated cost of producing electricity in a wood-fired plant at $0.54 /kWh, existing generating plants will be unable to operate profitably at current wholesale electricity prices which average well below this level.[6] Biomass plants using a conventional Rankine cycle (i.e. stoker fired boiler and steam turbine) operate at a nominal 21% efficiency with combined cycle operation increasing

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[3] Cole Hill Associates. *Bio-oil Commercialization Plan*. July 2004. available at http://nh.gov/oep/programs/energy/bioOil.htm
[4] Governor's Office of Energy and Community Services. *New Hampshire Energy Plan.* November 2002.
[5] Ibid
[6] Innovative Natural Resource Solutions LLC and Draper/Lennon, Inc. *Identifying and Implementing Alternatives to Sustain the Wood-Fired Electricity Generating Industry in New Hampshire.* January 2002.

efficiencies up to 40%.[7] Proponents of bio-oil claim efficiencies approaching 60% when using a direct-fired gas turbine, thus offering significant advantages over traditional combustion technologies.

Bio-oil is a liquid with handling properties similar to those of the heaver grade petroleum-based fuels. As such, bio-oil can be transported, stored and handled using equipment designed to handle the more traditional fuels. This is a significant advantage over other biomass fuels, which are expensive and cumbersome to transport. It has also been shown that bio-oil can, in some cases, be used directly in existing fossil fuel electricity generating facilities,[8] thus opening the possibility for direct entry into a market traditionally dominated by fossil fuels.

Bio-oil is produced from biomass, a renewable resource, and as such can be marketed as a "green" product. The combustion of bio-oil is considered to be CO_2 neutral. These environmental benefits coupled with the positive impact on local economies make it a viable candidate as an emerging business for New Hampshire. In an earlier study for New Hampshire's Office of Energy and Planning it was stated that:

> "By providing a market for local forestry products and by locating in proximity to the state's timber base, a bio-oil plant could be a significant contributor to rural economic development. Further, because bio-oil is produced from a renewable feedstock, it is considered by many to be carbon-neutral, and does not contribute to greenhouse gas emissions. This may make it possible for a bio-oil production facility or a facility using bio-oil to generate electricity, to participate in certain programs designed to encourage renewable energy generation, or to receive financial incentives for reducing atmospheric emissions of carbon." [9]

2.3 Applications of Bio-oil

In addition to use as a fuel for power and heat, bio-oil can serve as the base for the manufacture of a wide range of organic chemicals. The uses are introduced here and applicable uses discussed in depth later in this report.

2.3.1 Bio-oil as a "Green" Fuel

The nearest term commercial use of bio-oil is in generation of power and heat. With modest equipment modifications, bio-oil can be substituted for fuel oil or diesel in a number of static applications including stationary diesel engines, gas turbines, boilers and

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[7] DynaMotive Energy Systems Corporation and R. Thamburaj of Orenda Space Corporation. *Fast Pyrolysis of Biomass for Green Power Generation.* First World Conference and Exhibition on Biomass for Energy and Industry. 2000.
[8] Sturzl, Ray. *The Commercial Co-Firing of RTP™ Bio-oil at the Manitowoc Public Utilities Power Generating Station.* June 1997.
[9] Innovative Natural Resource Solutions LLC. *New Hampshire Bio-oil Opportunity Analysis.* September 2004. available at http://nh.gov/oep/programs/energy/bioOil.htm

furnaces. Bio-oil has been successfully test co-fired with coal, providing 5% of the BTU value to a 20MW boiler.[10] Bio-oil has a successful record of utilization in commercial boilers to provide industrial process heat and drying, and is approved for use in district heating utility boilers in Sweden.[11] ORENDA Aerospace Corporation has successfully tested bio-oil in its 2.5 MW combustion turbine-powered generator.[12]

Because, bio-oil is derived from renewable resources, a facility using bio-oil to generate electricity for sale may qualify for some programs designed to encourage renewable energy, such as Renewable Portfolio Standards (RPS) in neighboring states. An RPS is a regulatory requirement that any supplier of electricity must derive a specified portion of that electricity from renewable energy sources. Maine, Massachusetts, Rhode Island and Connecticut all have an RPS that allow biomass power plants to participate; Massachusetts and Connecticut have specific provisions that encourage the construction of new facilities that use biomass to generate electricity.[13]

2.3.2 Chemicals

A wide range of "green" chemicals can be extracted from bio-oil,[14] and are an attractive possibility to producers of bio-oil because they generally offer much higher value added products as compared to fuels and energy products. Chemicals can be isolated, extracted and processed to meet customer specifications, and the remaining bio-oil will still retain its value as a fuel. In order to recover specific chemicals for value-added use, it is necessary that these chemicals be present in the bio-oil in large enough quantity to allow for economic recovery. For wood-based bio-oil, such chemicals include hydroxyacetaldehyde, acetic acid, formic acid, levoglucosan and levoglucosenone.[15]

These chemical compounds have the potential to serve as the basis for a wide variety of chemicals. Food flavorings are extracted from bio-oil in a number of countries, including the United States. Researchers are also working on developing natural resins and polymers for use in engineered wood products; these have already undergone mill trials.[16,17] Additional tested uses of bio-oil include: as a base for organic wood preservatives, as an ingredient in slow-release fertilizer used in commercial agriculture,

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[10] Struzl, Ray 1997.
[11] Hogan, Ed, *The Pyrolysis Biorefinery Concept for the Production of Green Fuels and Chemicals.* Presentation by CANMET Energy Technology Center, Natural Resources Canada. August 16, 2002.
[12] Button, Frank of Orenda Aerospace Corporation. *Orenda Aerospace Corporation: Overview.* Presentation in Concord, NH. August 16, 2002.
[13] Database of State Incentives for Renewable Energy. *States with a Renewables Portfolio Standard.* April 2002.
[14] Bridgewater, Tony. *A Guide to fast Pyrolysis of Biomass for Fuels and Chemicals*. PyNe Guide 1, Aston University, UK. March 1999.
[15] Radlein, Desmond, of resource Transforms International Ltd., *The Production of Chemicals and Materials from Bio-oil.* in *Fast Pyrolysis of Biomass: A Handbook*, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp. 164-188.
[16] Boulard, David C. *Bio-oil: The New Crude.* Presentation by Ensyn Technologies, Inc. Concord, NH. August 16, 2002.

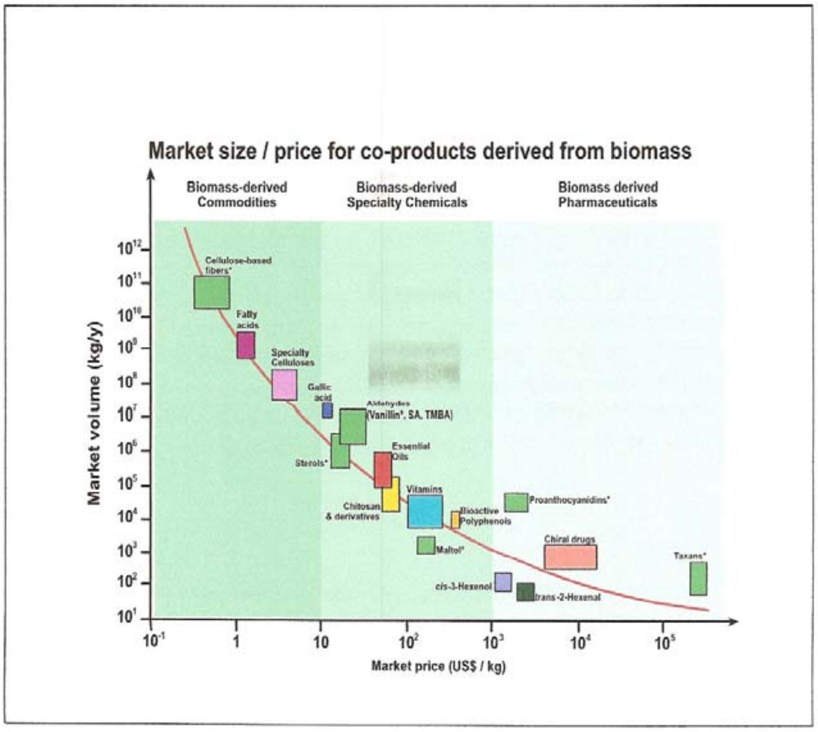

Figure 1. Potential Co-Products Derived From Biomass [18]

as an octane enhancer and as a hydrogen source. A product has been developed using bio-oil that serves as an emissions control agent for SO_x and NO_x in coal combustors.[19]

At a recent forum on bio-products in Maine[20], a number of chemicals and co-products were identified that can be derived from biomass, through the pyrolysis process. These included fatty acids (used as lubricants), sterols and gallic acid (used in the pharmaceutical sector), maltol (used as a food additive), proanthocyanidins (an antioxidant), and taxans (used in pharmaceuticals). Figure 1, presented at the forum[21], shows co-product chemicals that may be derived from biomass, and the price these chemicals may derive in the marketplace.

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[17] Graham, Robert G. *Use of Bark-Derived Pyrolysis Oils as a Phenol Substitute in Structural Panel Adhesives.* Final Report, U.S. Department of Energy, DOE Cooperative Agreement No. DE-FC 36-00GO10597. December 2003.
[18] Chornet, Esteban. *River Valley Pyrolysis Project.* March 2, 2004. University of Maine, Orono.
[19] Radlein 1999
[20] *Maine Bio-Products Forum: Converting Cellulose Into Sales.* University of Maine, Orono. March 2, 2004.
[21] Chornet 2004.

While "green chemicals" represent a significant potential market for bio-oil producers, it is important to note that many of these chemicals have not been successfully isolated from bio-oil, and the process necessary to isolate certain chemicals may prove uneconomical.

2.3.3 Bio-Refinery

Some advocates of bio-oil see it as the core product of a "bio-refinery" or "bioplex", where an economically optimum combination of energy, chemicals and materials are manufactured.[22] This is an integrated approach where the forest industry (and potentially the agricultural sector and municipalities) provides the feedstock and are the users of energy and chemicals from the bio-refinery. The energy and utility industries are potential investors, while serving as customers and distributors of energy and fuels. In the bio-refinery model, the government and manufacturing sectors play secondary roles, providing policy support and markets for the output.

2.4 Risk Factors: Economic and Technical

The production of bio-oil from the fast pyrolysis of wood chips is an emerging technology. There is no assurance that this technology will emerge as a significant source of alternative fuels and/or become an expanded source for value-added chemicals. As with most emerging technologies, much of the information necessary to establish a commercial plant is retained as proprietary information. There is limited public information available to validate and/or contradict many of the assumptions presented in this study.

Assumptions used in this report are based on the best available knowledge of the currently existing bio-oil technology and business conditions as they currently exist in northern New Hampshire. It is understood that assumptions may change based on differences relevant to proprietary technology and conditions unique to specific business groups and/or locations.

There is limited access to the technology. To date there are only three companies in North America capable of supplying the fast pyrolysis technology. Only one of these companies has demonstrated the ability to establish an economically operating commercial plant. The other companies are in various stages of demonstrating their first commercial plant. There is no assurance that any of these companies are interested in building a plant in New Hampshire and if so, that a viable business agreement could be reached with any of the principal suppliers. It may be deemed impractical to contract for, construct and/or operate a bio-oil facility in New Hampshire.

There are no commercially operating stand-alone plants. Existing commercial plants are integrated parts of other commercial processes and most, if not all, products generated by the plant are consumed onsite. Operating and financial information is retained as

[22] Hogan 2002

proprietary information. Much of the information provided in this report was obtained from private conversations and presentations made by the potential suppliers, "knowledgeable third party sources" and/or from academic studies.

Limited market data are available. To date sufficient quantities of bio-oil have not been available to establish a market. There is no assurance that a viable market will emerge. To use bio-oil as an alternative fuel, customers will need to invest time and money to convert boilers to burn bio-oil with no assurance of a sustained, reliable source of bio-oil. Value-added chemicals will need to compete with existing sources. Barriers to market entry are unknown and could be significant. It is uncertain how current market suppliers will react, e.g., reduce prices in an effort to eliminate competition. Without competitive sources the price of bio-oil and chemicals derived there from could be unstable and become economically prohibitive.

There has been no attempt to acquire the required local, state and federal permits and licenses necessary to operate a bio-oil plant and/or to utilize the products generated. Although a most likely region for a bio-oil facility has been suggested, a specific plant site has not been identified. This report relies on the fact that commercial plants exist in other U.S. States and in Canada. These plants have received the necessary permits without issue. There are also technical papers reporting the physical properties of bio-oil, as well as plant emissions.

Critical factors used in the economic analysis such as the price and availability of feedstock, capital cost, return on investment, cost of money, labor rates, energy credits and *etc*., are consistent with those currently being used in northern New Hampshire and surrounding New England states at the time of writing. These parameters may change with plant design, time, location, etc.

3. Bio-oil Production

3.1 Properties of Bio-oil Produced from Wood

Bio-oil is an organic liquid fuel produced from the fast pyrolysis of biomass such as whole-tree chips. Fast pyrolysis is a thermal process where-by biomass is rapidly heated in an oxygen-free environment to a controlled temperature with rapid quenching of volatile materials released by the destructive distillation of chemicals from the biomass.[23] While related to the traditional pyrolysis process for making charcoal, fast pyrolysis is an advanced process using a carefully controlled temperature to maximize yields of liquid. Essential features of fast pyrolysis are very high heating rates, very fast heat transfer rates requiring a finely ground biomass feed, carefully controlled reaction temperatures around 500C, and rapid cooling of the pyrolysis vapors. This process produces three products: liquid, char and gas. Distribution of products from fast pyrolysis is a function of the biomass feedstock and reactor conditions. For a biomass feedstock containing 5-15% water content, typical yields range between 45-80 wt% liquid condensate, 10-20% char and 10-30% gases.[24]

Pyrolysis liquid is referred to by many names including pyrolysis liquid, pyrolysis oil, bio-oil, bio-crude-oil, bio-fuel-oil, wood liquids, wood oil, liquid smoke, wood distillates, pyroligeneous tar, pyroligeneous acid, and liquid wood.[1,25] For the purposes of this report the liquid product resulting from fast pyrolysis will be referred to as "bio-oil".

In appearance, bio-oil is typically a free flowing liquid ranging in color from almost black through dark red-brown to dark green depending upon feedstock and pyrolysis conditions. The liquid has an acrid smoky smell. Bio-oil contains numerous chemicals in varying proportions ranging from low molecular weight chemicals such as formaldehyde and acetic acid to higher molecular weight chemicals such as phenols and anhydrous sugars.

The water content of bio-oil is typically between 15-30 wt% depending on the moisture content of the feedstock and pyrolysis conditions. Bio-oil has a lower hydrocarbon content than petroleum-based fuels, thus having a lower heat content approximately 55% that of light fuel oil or diesel and approximately 90% of ethanol. Bio-oil is a transportable liquid similar in properties to petroleum-based fuels. Its viscosity is between that of #2 and #6 fuel oil. Similar to diesel, it has a limited shelf life. This can be extended by storing at room temperature, in a closed container with periodic stirring and/or agitation. Bio-oil is more acidic (pH 2.5-3) than petroleum-based products and should be stored and handled using stainless steel and/or polyethylene containers and

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[23] Bridgwater, A.V., "An Introduction to Fast Pyrolysis of Biomass for Fuels and Chemicals" in *Fast Pyrolysis of Biomass: A Handbook*, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp. 1-13.
[24] Diebold, J.P. and Bridgwater, A.V. "Overview of Fast Pyrolysis of Biomass for the Production of Liquid Fuels" in *Fast Pyrolysis of Biomass: A Handbook*, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp. 14-32.
[25] Bridgewater, Tony A. 1999.

piping.[26] Limited studies to date indicate that bio-oil is no more hazardous than similar petroleum-based materials and should be handled using similar precautions.[27]

Physical Properties		**Typical Value**
Moisture Content		15-30%
pH		2.5-3.0
Specific Gravity		1.20
Elemental Analysis, dry basis	C	5.64%
	H	6.2%
	O (by difference)	37.3%
	N	0.1%
	Ash	0.1%
HHV as produced (depends on moisture)		16-19 MJ/kg
Viscosity (at 40C and 25% water)		40-100 cp
Solids (char)		0.5%
Distillation		max. 50% as liquid degrades

Characteristics

- Liquid fuel
- Easy Substitution for conventional fuels in many static applications – boilers, engines, turbines.
- Heating value is about 40% that of fuel oil or diesel on a weight basis and 60% on a volume basis.
- Does not mix with hydrocarbon fuels
- Not as stable as fossil fuels

Table 1. Typical properties and characteristics of wood derived bio-oil [28]

Extensive combustion studies have been performed with bio-oil generated from wood feedstock..[29,30,31,32,33,34] Results of these tests are summarized as follows.

[26] Lédé, J. Diebold, J.P., Peacock, G.V.C., and Piskorz, J. "The Nature and Properties of Intermediate and Unvaporaized Biomass Pyrolysis Materials" in *Fast Pyrolysis of Biomass: A Handbook*, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp. 14-32.
[27] Morris, Keith; Piskorz, Jan and Majerski, Piotr. BioTherm™: A System for Continuous Quality, Fast Pyrolysis BioOil. 4th Biomass Conference of the Americas, Oakland, CA. September 1999.
[28] Bridgewater, A.V.
[29] Sturzl 1997.
[30] Ensyn Technologies Inc. *Boiler Performance and Emission Compliance of Pyrolysis Oils.* Prepared for Natural Resources Canada, Ottawa, Ontario. Catalogue No. M91-7/24-1997E. October 1995.
[31] Wong, J.K.L., Banks, G.N. and Whaley, H. *Flame Tunnel Emissions Testing of ENSYN Liquid Bio-Fuels.* Canada Centre for Mineral and Energy Technology. May 1995.
[32] CSP Environmental Consultants, LTF. *Canmet Flame Tunnel Stack Air Emissions During Burning of Two Ensyn RTP Biomass Fuels.* Prepared for Ensyn Technologies Inc. March 1995.
[33] Hogan 2002.

To maintain an energy release rate equivalent to that for petroleum-based fuels requires a flow rate approximately 1.6 times that for # 2 fuel oil. Typical combustion parameters for burning bio-oil include an air atomizing burner and fuel handling system similar to that used for emulsified bitumen. Bio-oil is stored in a tank with the temperature maintained at approximately 36C and a blade impeller mixer to keep the fuel homogenized. Fuel is transported to the burner using a positive displacement pump and an in-line steam heat exchanger is used to obtain increased uniform fuel temperatures at the burner. Nominally preheated atomizing air (114C to 132C) is used and flue gas oxygen is maintained at about 5 to 5.5% (15-20% excess air). Although the bio-oil flow rate is increased, the airflow required to maintain effective combustion is reported as similar to that for the petroleum-based fuels.

	MJ/l	BTU/U.S. gallon
Bio-oil (wood)	21.0	75,500
Bio-oil (bark)	22.7	81,500
Fuel Oil #6	38.9	153,200
Fuel Oil #2	35.2	138,500
Methanol	17.5	62,500
Ethanol	23.5	84,000

Table 2. Comparative Heating Value of Fuels

The exhaust gases from bio-oil have a higher content of water vapor resulting in a slightly higher dew point for the stack gases, but values are well below normal exhaust temperatures. Composition of the flue gas shows higher CO_2 levels from the bio-oil and CO and NO_x levels close to those for #2 fuel oil but lower than those for burning #6 fuel oil. SO_2 emissions from the combustion of bio-oil are dramatically lower than those for petroleum-based fuels. At lower bio-oil flow rates, i.e. lower heat transfer rates, and lower flame temperatures, NO_x emissions are substantially reduced. For bio-oil flow rates comparable to #2 fuel oil, NO_x emission is reduced by approximately 50%. This is because of the low fuel nitrogen content with most of the NO_x coming from air nitrogen. Particulate emissions tend to be higher than those for #2 oil and about the same as for #6 oil; roughly correlating with the ash content of the bio-oil.

Emissions are influenced by the quality of the bio-oil, in particular the char/ash content, and by the bio-oil contaminants which are dictated by the composition of the biomass feedstock from which the bio-oil was produced. A significant destruction of dioxins/furans (up to 99%) occurs during combustion. From the reported combustion studies, it is reasonable to expect that combustion systems for fuel oils can be converted to use a reasonable quality of bio-oil without producing emission levels that would prevent permitting in normal situations.

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[34]Ensyn Group Inc. *Bio-oil Combustion Due Diligence: The Conversion of Wood and Other Biomass to Bio-oil. June 2001.*

Char is the other major pyrolysis product. The quality of char produced is dependent on the feedstock. Whole tree chips of either hard wood, soft wood, or a mixture results in a high quality char product. The char is typically used in the process as a fuel for drying the feedstock. If dry feedstock is available and/or alternative fuels are available to operate the pyrolysis process, the char can be sold as a high quality fuel (i.e. charcoal briquettes) and/or converted into activated carbon. The LHV of chars has been reported to be approximately 14,000 BTU/lb.[35] The ash content of char is about 6 to 8 times greater than that of the feedstock. Because the ash is concentrated in the char, the alkali content of the char is quite high. The high ash content in the char causes fouling and corrosion problems during combustion similar to those found in other high ash fuels such as coal. The low temperature of ash slagging and alkali vapor deposition lead to the higher fouling and corrosion.

Gas produced by pyrolysis is used in the process as a fuel and as a carrier gas. The LHV for the gas is approximately 390 BTU/SCF.[36] The use of pyrolysis gases as a synthesis gas to produce higher value products would require extensive reforming. Due to the unfavorable economy of scale, it probably will not be feasible to use pyrolysis gas as a synthesis gas.

3.2 How Bio-oil is Produced

Bio-oil is an organic liquid fuel produced by a process known as fast pyrolysis. Fast pyrolysis is a high temperature process whereby biomass, such as wood chips, is rapidly heated in the absence of oxygen producing a gas stream containing volatile organic material and aerosols. Rapid quenching of the gas stream produces a condensate known as bio-oil. Pyrolysis typically occurs at 500C or less resulting in the destructive distillation of chemicals from the biomass. The process is carried out at low temperatures to maximize the yield of liquid product. An added benefit to operating at lower temperatures is that the process minimizes the production of hazardous chemicals such as dioxins and furans from the thermal decomposition (i.e. cracking) of higher molecular weight organic molecules. Essential features of fast pyrolysis are:

1. very high heating and heat transfer rates which require the moisture content of the feedstock to be 5-8% and feedstock to be finely ground to a particle size of approximately 2mm.
2. carefully controlled pyrolysis reaction temperatures with short vapor residence times of typically less than 2 seconds, and
3. rapid cooling of the pyrolysis vapors.

Most commercial processes involve some form of a fluidized bed reactor. DynaMotive Energy Systems Corporation uses a bubbling fluid bed, which is conceptually shown in Figure 2. Bubbling fluid bed reactors are characterized by exhibiting good temperature

[35] Bridgwater, A.V 1999
[36] ibid

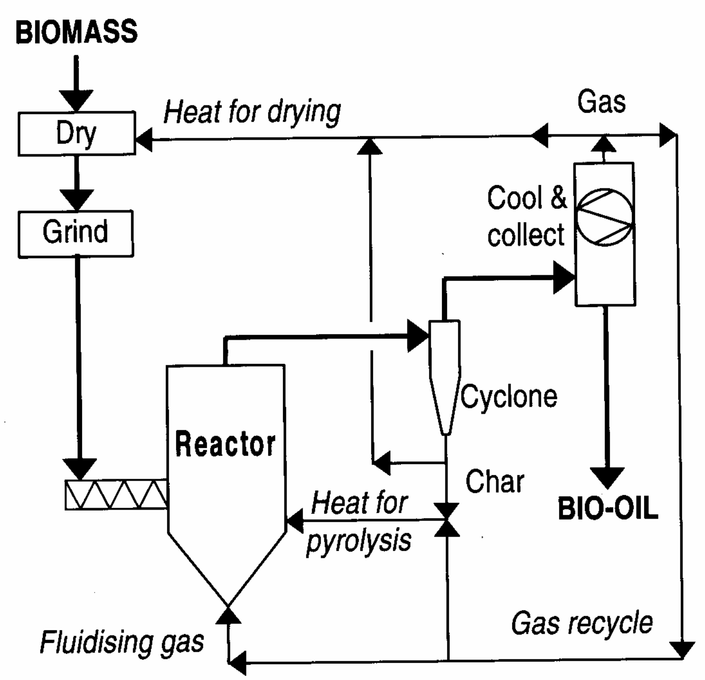

Figure 2. Conceptual Fluid Bed Fast Pyrolysis Process[37]

control, easy scalability, well understood technology and are commercially operational. On the negative side, however, bubbling fluid bed reactors require small particle sizes and adequate heat transfer to the bed for large scale systems has not been proven. Using this type of system, DynaMotive has bench tested over fifty feedstocks including wood, wood manufacturing residue, agricultural products and residues, municipal solid waste, pulp mill sludge, peat, and newsprint.[38]

An alternative fluid bed configuration is the circulating or transported bed reactor used by Ensyn Group Inc. in their RTP™ process. Transported bed reactors have characteristics similar to those of the bubbling fluid bed reactor. A conceptual design of the RTP™ process is shown in Figure 3. Ensyn has several commercial facilities using this type of reactor to produce food flavorings and related chemicals extracted from the pyrolysis liquid. Ensyn has tested hardwoods, softwoods, hardwood bark, softwood bark, corn fiber, bagasse and waste paper for the production of bio-oil.[39]

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[37] Ibid

[38] DynaMotive Energy Systems Corporation. *Bench Tested BioTherm Feedstocks.* available at www.dynamotive.com

[39] Ensyn Group, Inc 2001.

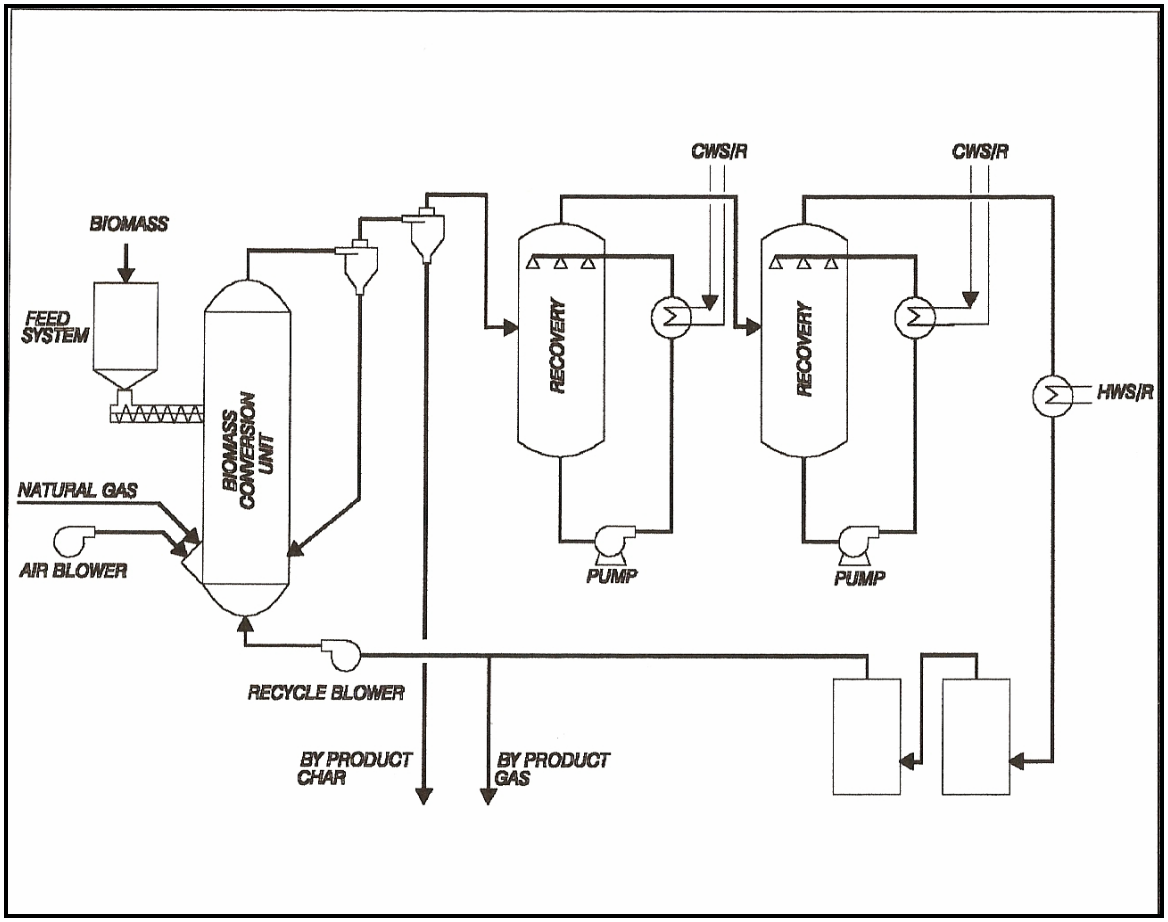

Figure 3. Simplified Process Flow Diagram for Ensyn's RTP™ Process[40]

Other reactor configurations and processes have been bench tested; however, none have been proven commercially. The most promising of this group is a patented process by Renewable Oil International, which uses a specially designed, indirectly heated auger.[41] Proposed advantages are that the process does not require an inert gas stream to fluidize a bed or transport hot sand. Elimination of the recycle blower and the associated heat load is reported to greatly reduce the capital and operating costs.

[40] Graham, Robert G. 2003.
[41] Renewable Oil International. Presentation at Bio-oil Briefing Workshop, Concord, NH. August 2002.

4. Feedstock Availability

4.1 New Hampshire Forest Industry

New Hampshire is the second most densely forested state in the nation with 84% of the land covered in forest.[42] Most of New Hampshire's forest (70%) is family owned with the average size woodlot of just less than 40 acres. As a renewable resource, New Hampshire's forests provide a wide variety of products as well as being a source of aesthetic and recreational enjoyment. They provide a habitat for wildlife and act as a natural filter, assuring water quality. Maintaining a viable forest products industry through sustained management of forested lands is vital to the well being and economic development of both New Hampshire and the northeastern region of the United States.

New Hampshire's forest industry includes timber harvesting and trucking, primary processing, wood products manufacturing, pulp and paper making and wood energy production. In 2001, logging operations generated $37 million in financial return to NH's landowners and almost $4 million in tax revenue's to municipalities. 255 million board feet of softwood and 62 million board feet of hardwood were harvested and almost 1.15 million green tons of whole tree chips (biomass chips) were delivered to the state's wood energy plants.[43]

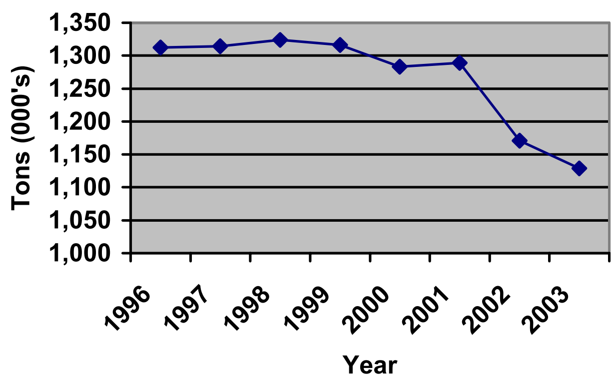

Figure 4. Whole Tree Chips Delivered per Year [44]

In the 1980's, biomass electric power plants were established in New Hampshire in an effort to create energy diversification and a new market for wood chips (low grade wood products). This market place was strongly supported by forestry, wood products and conservation organizations because the policy encouraged good forestry practices, increased land value, provided a market for sawmill residue, created jobs, and supported

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[42] University of New Hampshire Cooperative Extension. available at http://ceinfo.unh.edu/Forestry/FORIND.htm

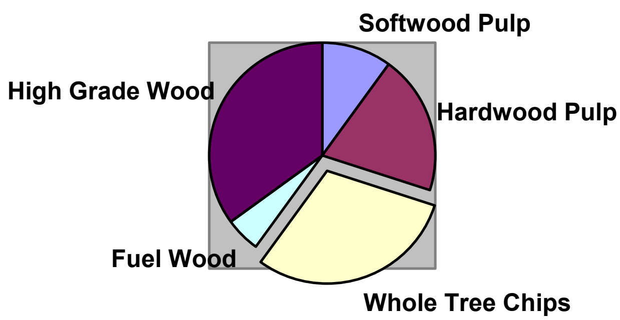
[43] The closing of Bio Energy was the primary cause for the decline in whole tree chip deliveries starting in 2001.

[44] Innovative Natural Resource Solutions LLC 2004.

conservation movements. By 1990, eight privately-owned biomass electric power plants were operating in NH producing approximately 6% of the state's electrical power and consuming 1.2 million tons of whole tree chips per year.

The wood-chip market is an important part of the overall forest products industry in NH. The NH Division of Forests and Lands reported that 30% of the wood harvested in 2001 was whole tree chips. Whole tree chips, i.e. biomass, are the fuel used in wood-fired electric power plants. Whole tree chips are produced mostly in the woods and are made of low-grade and small trees including the leaves, branches and bark as well as wood fiber. A report of the New Hampshire Timberland Owners Association stated:[45]

> "This market provides an outlet for low grade wood, material that is neither suitable nor economical to process for lumber or paper. This market helps provide income for the logger and economic incentive for the landowner to improve the quality of the forest, thus promoting better forest management."



Based on Tax Year 2001
Source: NH Division of Forest Lands

Figure 5. New Hampshire Forest Products

Biomass power plants operate under a rate order structure, which augments grid prices and assures economic viability. At present five plants remain operational with three plants having opted for early buyout and subsequent closure. A fourth plant, Whitefield Power & Light opted for early buyout, however, continues to operate under new ownership. By investing in new technologies, Whitefield Power & Light qualifies under Connecticut's renewable portfolio standard. By selling its RPS credits, WP&L is currently able to operate profitably. Remaining rate orders will terminate in 2007-8 with the continued operation of the remaining plants uncertain.

[45] New Hampshire Timberland Owners Association, "The New Hampshire Forest Industry", 2001. available at www.nhtoa.org/nhforestindustry.htm

With the possible closure of the existing biomass power plants, Public Service of New Hampshire has announced a plan to build a new 50 megawatt wood-fired boiler at its Schiller Station near Portsmouth. This new facility would burn up to 400,000 tons of clean wood chips annually which represent approximately 33% of the current whole tree chip market in New Hampshire. By selling the renewable energy credits generated by the new boiler to newly established markets for green power in Massachusetts and Connecticut, PSNH will be able to offset the initial capital investment costs.

Assuming closure of the wood-fired power plants at the termination of their rate orders, the market for whole-tree chips will shrink dramatically in coming years, even with the start up of the proposed Schiller Plant.[46]

Overall, the forest products industry in New Hampshire faces a number of challenges, including high energy demand, staff training and retention, decrease in harvested wood and declining markets. At a meeting sponsored by NH Industries of the Future, John King owner of King Forest Industries, Inc. made the following observation:

> "In addition to slowing markets, labor costs have increased. At the same time that workforce training and insurance costs have increased; mill owners are faced with product that is not moving into markets. In the past five years there has been a drastic decline in the quality of logs available to the sawmills; much of the state's most valuable timber is located in areas that are not available for logging."[47]

Concerns of the timberland owners are consistent with timber supply projections for northern New England as presented in a 2003 study.[48] The 2003 study projects that New Hampshire will lose as much as 1,038,000 acres representing 22% of the forested lands over the next 50 years. This loss is by far the greatest for any New England state. Currently, the commercial clear cutting on a 22,500 acre parcel in Success, New Hampshire has renewed the controversy over whether heavy logging in the North Country threatens future wood supplies for the state's forest products industry, primarily lumber and paper mills and wood-fired power plants. The concern for loss of forest lands has led the New Hampshire Timberland Owners Association and the Society for the Protection of New Hampshire Forests to announce a joint study of North Country logging. Goals of the study are to examine current and past rates of timber harvesting and tree growth and to look at the long-term wood supply for the states forest industry.[49]

Access to reliable information about the forested resources is critical to sustain both the industry and the forest. Unfortunately, there is very little current information available

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[46] Biomass power plants could continue to operate assuming changes in operating parameters such as investments in new technology, participation in renewable power programs, changes in fuel type and/or cost, changes in the wholesale electricity market and/or other factors.

[47] www. nhiof.org/april24/sawmill.asp

[48] Sendak, Paul E. et.al., "Timber Supply Projections for Northern New England and New York: Integrating a Market Perspective, *NJAF 20(4) 2003.*

[49] Foster's Daily Democrat, July 20, 2005.

on industry performance. The need for current and reliable data was expressed in the April 1996 New Hampshire Forest Resources Plan.[50]

> "While several sources of information are currently available there is insufficient information on some issues vital to sustaining our forests. In some cases information is not being collected. In others, the system for collecting data is not through or timely. New Hampshire depends on the U.S. Forest Service decennial Forest Inventory and Analysis (FIA) for data on the status of timber and other forest resources. However, FIA inventories are conducted at unpredictable intervals and do not collect comprehensive information about all biological elements of the forest……..Increased efforts to coordinate research are needed to provide landowners and resource managers with the information they need to make informed decisions."

In 1997 the NH Forest Industry Task Force was established to investigate ways to promote and expand wood using companies, develop new markets for lower grades of timber and to replace markets lost by downsizing and closing of wood fired electrical generating plants. This led to a three-phase study on the use of low-grade wood in New Hampshire.[51] This study confirmed the importance of low-grade wood market to sustainable forestry and the viability of forest industries. It also concluded that in the foreseeable future there are no alternative manufacturing facilities to replace existing markets for low grade wood.

Economic trends, logging practices and long-term industry projections based on the extrapolation of 1990's data generate concern as to the future of the forest products industry in New Hampshire and the industry's ability to support sustained economic growth and future development. Relevant to this report is the concern over the long-term availability of low-grade wood chips for a biomass industry given the continued decline in whole-tree chip production. If this trend continues, there will be little incentive for the landowner to improve the quality of the forest through better forest management and it will thus be a deterrent to any new biomass related business considering locating in New Hampshire. Stopping the current declining trends in New Hampshire's timber industry and thus have any hope for attracting new timber related industries, such as bio-oil, will require a detailed economic development plan aggressively implemented by local communities with the support and committed leadership of state government. Such a plan with specific details of economic support available from state and local governments would be invaluable in helping to attract new business, such as a bio-refinery, in support of the forest industry in New Hampshire.

[50] Forest Resources Plan Steering Committee and New Hampshire Department of Resources and Economic Development, Division of Forests and Lands. April, 1996.
[51] Innovative Natural Resource Solutions LLC 2002.

4.2 Feedstock Availability and Pricing

4.2.1 Introduction

The availability and pricing of wood for a bio-oil facility is a crucial piece of information for determining the feasibility of a bio-oil facility in New Hampshire. In general, New Hampshire has a significant amount of low-grade wood.[52] The state's five operating wood-fired power plants, pulp mills in Berlin and Groveton, as well as, energy and pulp markets outside of New Hampshire provide a number of outlets for this material. At present, the logging and trucking infrastructures exist to harvest, process and transport whole-tree chips, pulpwood, and sawmill residue. It is possible that, as some of the wood-fired power plants cease operations, this infrastructure will decline, particularly for whole-tree chips.

4.2.2 Suggested Bio-oil Plant Location for New Hampshire

The Town of Whitefield is located in Coös County, the northernmost county in New Hampshire. A fifty-mile radius around Whitefield includes parts of Coös, Grafton and Carroll counties in New Hampshire; parts or all of Essex, Orleans, Caledonia, Lamoille, Washington, and Orange counties in Vermont; part of Oxford County in Maine; and a very small part of the Province of Quebec (Figure 6). Because of the abundant forest land, robust market for wood chips and associated forest related industries, it is felt that the region centered on Whitefield, NH would be the most reasonable location for a bio-oil facility in New Hampshire.

4.2.3 Land Ownership

Non-commercial forest landowners, the most common type of landowner in New England, can own from one acre to hundreds of thousands of acres. Each landowner manages land for different reasons and with different economic requirements, so it is difficult to make statements about management on certain parcels of land. However, taken as a whole, non-industrial private landowners are the primarily suppliers to New Hampshire forest industries, and as a group provide a steady and consistent level of timber to the market.

Commercial forest lands are owned and managed primarily for the purpose of timber production, and are owned by firms with forest products manufacturing facilities. Harvested timber that does not fit a manufacturing facility's species or grade parameters, or is in excess of the facility's needs, is often sold to other forest industries.

Speaking broadly, public lands in the region harvest less timber *on a per acre basis* than other types of landowners. This is because most public lands are managed for multiple.

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[52] Frieswyk, Thomas and Richard Widmann. *Forest Statistics for New Hampshire: 1983 and 1997*. USDA Forest Service, Northeast Research Station Resource Bulletin NE-146. April 2000.

Figure 6. 50 Mile Radius – Whitefield, NH

benefits, and timber production is generally one of many competing and compatible land uses (others would include recreation and wildlife habitat, for example).

The entire White Mountain National Forest is located within 50 miles of Whitefield. New Hampshire's largest state forest, Nash Stream, is located within 50 miles of Whitefield. Additionally, large tracts of industry-owned and investor-owned land are located within 50 miles of the town, as well as large areas of forest land in New Hampshire, Vermont and Maine owned and managed by non-industrial private landowners.

4.2.4 Other Industries Using Low-Grade Wood

In New England, the major industries that use low-grade wood are wood-fired power plants and the region's pulp mills.[53] New Hampshire has eight wood-fired power plants, five of which are presently operating. These five facilities use a little over one million tons of wood each year. These facilities operate under rate orders, which in effect guarantee that power from these facilities will be sold at a predetermined (and generally above-market) price. As these rate orders expire, these facilities face a very uncertain future in the competitive generation market.[54]

Northern New Hampshire has the state's most robust market for low-grade wood. This is because a number of paper mills and wood-fired power plants operate in or near the region. New Hampshire has two pulp mills, both located in the northern part of the state. These mills, located in Berlin and Groveton, have a historic wood use of 1.4 million tons of wood per year. New Hampshire landowners also sell wood to mills in other New England states, New York, and nearby Canada. It is estimated that New Hampshire harvests a total of 2.8 million tons of pulpwood each year.[55] The following facilities that purchase or use a significant volume of low-grade wood are located within 50 miles of Whitefield:

- The Burgess Pulp Mill is located in Berlin, NH. This mill, currently owned and operated by Fraser Nexfor, restarted operations in the Spring of 2003. Traditionally, this mill has used over 1 million tons of pulpwood annually. At present, this mill is purchasing hardwood pulpwood for its operations.
- Whitefield Power and Light is a 13.8 MW wood-fired power plant located in the town's industrial park. This facility, which consumes almost 190,000 tons of whole tree chips each year, had its rate-order bought out by Public Service Company of New Hampshire in 2001. It is currently owned by Conduit Energy LLC, and has added new emissions control equipment in order to qualify for premiums associated with an out-of-state a renewable portfolio standard.[56]
- Pinetree Power – Bethlehem is a 15 MW wood-fired power plant in Bethlehem, NH. This facility, which operates under a rate order that expires in November 2006, uses roughly 220,000 tons of whole-tree chips annually.
- Pinetree Power – Tamworth is a 20 MW wood-fired power plant in Tamworth, NH in Carroll County. This facility, which operates under a rate order that expires in March 2008, generally uses over 300,000 tons of whole-tree chips annually.
- Bridgewater Power is a 15 MW wood-fired power plant in Grafton County. This facility, which operates under a rate order that expires in August 2007, uses over 230,000 tons of whole-tree chips each year.

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[53] Innovative Natural Resource Solutions LLC and Draper/Lennon, Inc. *Use of Low Grade and Underutilized Wood Resources in New Hampshire.* Prepared for the NH Department of Resources and Economic Development. January 2001.
[54] Innovative Natural Resource Solutions LLC 2002.
[55] Howard, James. *U.S. Forest Products Annual Market Review and Prospects, 1999-2000.* USDA Forest Service, Forest Products Laboratory, Research Note FPL-RN-0278.
[56] Tucker, Edith. "Whitefield Power & Light; Permit sought for emission reduction unit." *Coos County Democrat.* August 18, 2004.

- Ryegate Power Station is a 22 MW wood-fired power plant in Ryegate, Vermont. This facility, which operates under a rate order that expires in 2012, uses roughly 250,000 tons of whole-tree chips, mill residue and wood chipped on-site each year.
- In addition to these facilities, several paper companies have log yards and/or chipping facilities within 50 miles of Whitefield. Carrier Chipping has a facility in Shelburne that primarily supplies Mead Westvaco's mill in Rumford, Maine; International Paper has a log yard in Freedom, NH that supplies its Jay, Maine mill, and SAPPI has a chipping facility in Ossipee, NH used to supply its Maine mill.

4.2.5 Timber Growth

The USDA Forest Service conducts an inventory and analysis of timber growth on a statewide basis every ten to fifteen years. This inventory, known as the Forest Inventory and Analysis (FIA), is in the process of becoming updated on an annual basis. However, this annualized information is not yet available for New England states. As a result, all information provided on harvest and removals is based on earlier FIA data:

- New Hampshire, 1997
- Maine, 1995
- Massachusetts, 1998
- Vermont, 1997

With existing markets for sawlogs, veneer and low-grade wood, the area within a 50-mile radius of Whitefield, New Hampshire has timber growth in excess of removals (from timber harvest or land conversion). It should be noted that within this radius is the entire

	Net Growth[55]	Harvest Removals	Land Use Removals	Net Change
		tons		
Spruce-Fir	578,382	(863,799)	(95,896)	(381,313)
White Pine	804,513	(411,348)	(43,565)	349,600
Hemlock	392,218	(158,944)	(27,492)	205,782
Other Softwood	68,621	(46,081)	-	22,540
Red Maple	966,955	(398,045)	(18,842)	550,068
Sugar Maple	734,393	(272,358)	(34,412)	427,624
Yellow Birch	219,776	(200,995)	(20,953)	(2,172)
Paper Birch	119,692	(229,779)	(72,066)	(182,153)
Beech	357,882	(190,626)	(11,042)	156,214
White Ash	180,868	(76,104)	(7,861)	96,904
Poplar species	149,485	(198,885)	(5,751)	(55,151)
Oak species	337,480	(172,885)	(5,934)	158,661
Other Hardwood	84,729	(27,835)	(1,713)	55,181
All Species	*4,994,995*	*(3,247,682)*	*(345,527)*	*1,401,786*

Table 3. Estimated annual forest growth and removals within a 50-mile radius of Whitefield, NH.[57]

[57] USDA Forest Service Forest Inventory and Analysis for New Hampshire, Vermont, Massachusetts and Maine.* All live trees >4.9"diameter at breast height.

[55] "Net growth" refers to the gross growth of a species in the forest less mortality (natural death) and other natural losses.

White Mountain National Forest, which has seen declining timber harvests in the past decade and future harvest levels from this land are uncertain. FIA data show that, for all species, growth exceeds removals by 1.4 million tons. Growth is greater than removals for all major species in the region except spruce and fir, yellow birch, paper birch, and poplar. The species red maple, sugar maple, white pine and hemlock show significant net growth (growth less removals).

4.2.6 Whole Tree Chips

Whole-tree chips are the product used to fuel most biomass-fired power plants in the region. Whole-tree chips are produced by running treetops, branches, and other wood through a chipper located at the landing of a logging operation. Whole-tree chips can be made from any species, and species are generally freely mixed. Though it varies by season and species, whole-tree chips are generally considered to have 40% - 50% moisture content (in other words, roughly half their weight is comprised of water).

Because of their use in the region's wood-fired power plants, as well as in some industrial boilers, there are good data on whole-tree chips prices in New Hampshire. The New Hampshire Timberland Owners Association reports prices for a wide variety of forest products, including whole-tree chips, on a quarterly basis.[58] This information is reported for three regions of the state.

Northern New Hampshire has the state's strongest and most consistent market for whole-tree chips. Between the third quarter of 1995 and the first quarter of 2003, the average

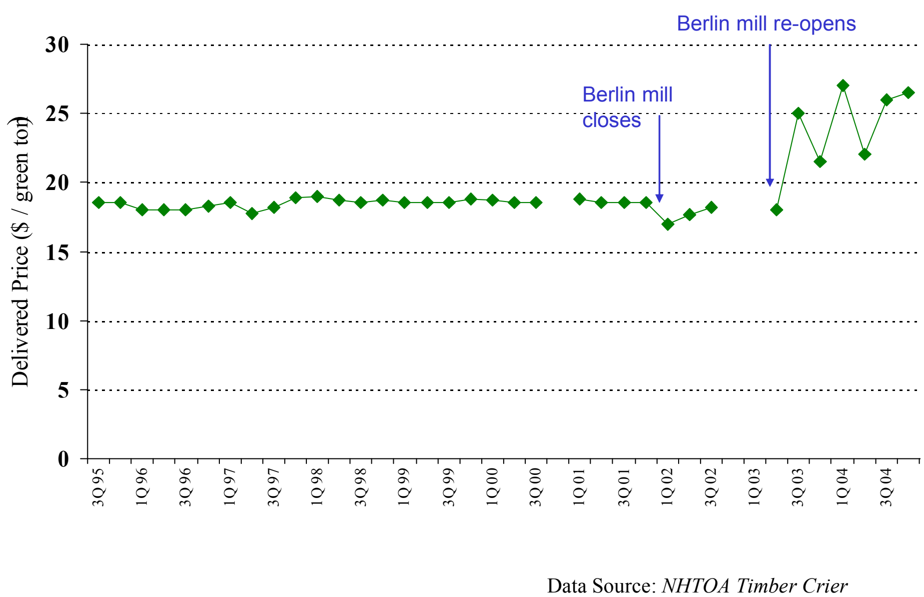

Figure 7. Delivered Price, Whole Tree Chips, Northern NH (per ton)

[58] New Hampshire Timberland Owners Association. "Quarterly Forest Products Market Report" section of the Timber Crier. 1995-2004.

price for whole tree chips in this region was $18.40 /green ton delivered; however, current prices are approaching $26 /green ton delivered as shown in Figure 7.

At present, the vast majority of whole-tree chips are sold on the open market, without long-term contracts that assure a fixed market and price for suppliers. It is possible that, if a facility were to provide long-term contracts to suppliers that assured a market and price, that whole tree chips could be acquired for less than current open market price.

4.2.7 Sawmill Residue

Sawmill residue is the by-product of lumber manufacturing, produced when round logs are sawed into boards. Sawmill residue is generally in two categories: chips and sawdust. Because bark is removed from logs prior to sawing, mill residue generally has very low bark content. It should be noted that mill chips have relatively high moisture content, generally from 50-60% depending upon species and time of year, because the chips are largely from the outside layers of the tree, where moisture content is the highest. Green sawdust has moisture content of roughly 40-50%, depending upon species, season and other factors. As a very limited quantity of dried sawdust is available in the region, all sawdust referenced in this analysis should be considered “green”.

A number of sawmills operate within a 50-mile radius of Whitefield. There are hardwood, white pine, spruce-fir and other mills in this region. These mills produce roughly 188,000 tons of sawmill residue each year, including almost 30,000 tons of sawdust. Self-reported weighted average pricing (delivered) for this residue is $18.00/ton for hardwood mill chips, $27.50/ton for softwood mill chips, and $10.50/ton for sawdust. At present, this residue is used in either paper mills or wood-fired power plants in the region. Although not confirmed, it is assumed that these prices have shown an increase similar to that for whole tree chips.

	Sawmill Chips							
	White Pine	Red Oak	Other Softwood	Other Hardwood	Total Softwood	Total Hardwood	Sawdust	Total
Annual Tons	93,900	3,480	2,220	59,520	96,120	63,000	29,760	188,880
Daily tons	257	10	6	163	263	173	82	517

Table 4. Sawmill Residue Within 50 Mile Radius of Whitefield, NH.

At present, some sawmill residue (both mill chips and sawdust) is sold on the open market without long-term contracts that assure a fixed market and price for mills. It is possible that, if a facility were to provide long-term contracts to mills that assured a market and price that mill residue could be procured for less than current pricing.

5. North American Suppliers of Bio-oil Technology

There are three companies in North America utilizing fast pyrolysis to produce bio-oil and other related products. These are Ensyn Technologies, Inc. (Ensyn), DynaMotive Energy Systems Corporation (DynaMotive) and Renewable Oil International (ROI).

5.1 Ensyn Technologies, Inc.[59,60]

Ensyn is the oldest of the three companies, having been in existence since 1984. It is based in Ottawa, Ontario, Canada, with its parent company Ensyn Group, Inc. located in Boston, MA. Ensyn utilizes Rapid Thermal Processing (RTP™) technology; a transported fluidized bed in which a continuous stream of hot sand supplies the heat required for rapid feedstock vaporization.

Ensyn is the only company with existing, operational commercial plants. The first commercial plant began operation in 1989. Ensyn currently has six (6) commercial plants in operation. The largest processes 45 tons per day of dry wood for production of food flavorings and by-product energy. Residual bio-oil and char products are being used for process facility heat as well as generating electricity. Ensyn is constructing a new 50,000 sq.ft. facility in Renfrew, Ontario, Canada to house a new bio-refinery, which will be capable of processing 60 tons of dry feedstock per day. This plant is expected to be fully operational by the end of 2005. This will be the first RTP™ facility to integrate the production of multiple commercial products with electricity generation.

Ensyn's business philosophy is to control their business by maintaining patented and proprietary technology. Ensyn will manage and operate facilities owned by the Ensyn Group or as a partner in joint ventures with other business partners and/or investor groups.

Ensyn is promoting a bio-refinery approach analogous to a petroleum refinery where raw bio-oil and solid carbon products are produced from low-grade wood. The bio-oil and carbon are then refined to produce a broad spectrum of value-added fuel, chemical and carbon products. The products include resins, polymers, emulsifiers, food flavorings and activated carbon, as well as, heat and electricity generation from the residual bio-oil from the refinery process. Products from the bio-refinery are from an abundant renewable resource, are greenhouse gas-neutral, extremely low in sulfur content and replace products from non-renewable petroleum resources. Examples of commercial products include:

1. NR, a natural resin ingredient used as a substitute for phenol and formaldehyde in wood panels,
2. V-Additive, a binder-emulsifier used in the non-wood construction industry,

[59] Ensyn Technologies, Inc. web site, www. ensyn.com
[60] Boulard 2002.

3. Food additives and products including flavorings, browning agents and activated carbons for de-colorization,
4. Bio-fuels such as solid charcoal and liquid fuels, and
5. Green power, with electricity generated using the bio-oil products.

In addition to commercial plants, Ensyn also maintains its own R&D laboratory, which explores a wide variety of new applications and products from a diverse range of renewable feedstocks. This facility houses two RTP™ pilot scale units.

5.2 DynaMotive Energy Systems Corporation.[61,62,63]

DynaMotive was incorporated in 1991 and is located in Vancouver, British Columbia, Canada. DynaMotive is a Public Company listed with the U.S. Securities and Exchange Commission and its stock traded "over-the-counter"(OTCBB: DYMTF). The Company uses a patented BioTherm™ process[64], which was acquired from Resource Transforms International (RTI) in February 2000. The BioTherm process utilized a deep bubbling sand fluidized bed technology combined with a novel bio-oil recovery system. Depending on feedstock, the process produces 60-75% liquid bio-oil, 10-20% solid char and 10-20% non-condensable gas. The char is used as a fuel for drying the feedstock and the non-condensed gas is recycled and used to heat the fluid bed and as the fluidizing gas. Bio-oil composition is 20-25% water, 25-30% water insoluble pyrolytic lignin, 5-12% organic acids, 5-10% non-polar hydrocarbons, 5-10% anhydrosugars and 10-25% other oxygenated compounds.

The company's business strategy is to be an energy solutions / energy service provider. Revenues will be generated from project opportunities through technology license fees, design/engineering fees, bio-oil/char royalties and /or project equity participation. To achieve these goals DynaMotive has entered into an agreement with RTI to acquire exclusive worldwide patent rights to the BioTherm technology; is working with Orenda Aerospace, a subsidiary of Magellan Aerospace Corporation to develop a bio-oil fueled commercial micro turbine package to produce electricity by the direct firing of bio-oil[65,66]; and has formed a strategic alliance with TECNA S.A. which allows DynaMotive to access Tecna's global design engineering expertise for plant design and construction.

DynaMotive built a 0.5-tpd prototype in 1997, which was upgraded in 1998 to a 2-tpd pilot facility. This pilot facility was operated for over 3,000 hours. In 1999, Stone and Webster Engineering, a major US based power engineering company, completed

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[61] DynaMotive Energy Systems Corporation web site, www. dynamotive.com
[62] DynaMotive Energy Systems Corporation 2002.
[63] DynaMotive Energy Systems Corporation. United States Securities and Exchange Commission Form 20-F. December 2004. www.sec.gov/Archives/edgar/data/941625/000094162505000020/form2of.txt
[64] Piskorz, et.al. United States Patent No. 5,728,271. "Energy Efficient Liquefaction of Biomaterials by Thermolysis." March 1998.
[65] Morris, Keith; Johnson, Warren; and Thamburaj, Raj. *Fast Pyrolysis of Biomass for Green Power Generation.* 1st World Conference and Exhibition on Biomass for Energy and Industry, Seville, Spain. June 2000.
[66] Magellan Aerospace Corporation. Presentation at Bio-oil Briefing Workshop, Concord, NH. August 2002.

technical due diligence and concluded that the process was 'reliable and scaleable." In 2001, a 10-tpd pilot plant was commissioned which has a production capacity of 6,000 liters of bio-oil per day. In January 2003, the Company closed its test facilities.

DynaMotive expects to commission the first of two commercial plants in the 3rd Quarter of 2005. The first will be a 2.5 MW cogeneration plant to be located at the Erie Flooring and Wood Products facility in West Lorne, Ontario. Magellan Aerospace Corporation – Orenda Division will provide the direct-fired gas turbine. This will be a pyrolysis oil fueled power co-generation facility. It will demonstrate the commercial potential in improving the efficiency of energy recovery from conversion of biomass to generate electric power from less fuel than traditional methods that use solid biomass combustion. The plant is expected to process 100 tons per day of biomass and to produce 70 tons of bio-oil, 20 tons of char and 10 tons of non-condensable gases. Fifty tons of bio-oil per day will be utilized to fuel a gas turbine developed by Orenda to produce up to 2.5 MW of electricity to meet the power requirements of the Erie Flooring plant and also export electricity to Ontario's energy grid. Surplus heat generated by the turbine will produce up to 12,000 pounds of steam per hour to provide heat for the Erie Flooring's industrial operations. The remaining bio-oil and char from the plant will be sold to commercial users and used for research purposes. Non-condensable gases will be used to provide heat to the process. Funding for the project has come from Sustainable Development Technology Canada (US$ 4.1 million capital grant) and Technology Partnerships Canada (TPC) (maximum funding cap of US$ 6.8 million) for its commercial scale development and testing program.

A third-party agreement has been signed with Megacity Recycling, Inc., for DynaMotive's second commercial plant. This will be a 200-tpd plant to be located in Ontario, Canada. This facility will also be supported by Technology Partnership Canada. It has also been disclosed that E&R Langille Contracting Ltd. Of Nova Scotia is analyzing the feasibility of developing a 500 tonne per day facility near the port of Pictou in Nova Scotia. The plant would be completed in two stages; a 200-tpd plant similar to Megacity Recycling followed by additional modules to be added later.

5.3 Renewable Oil International [67,68]

Renewable Oil International (ROI) is a small two-person start-up operation located in Florence, AL, USA and Ottawa, Ontario, Canada. The company was formed in 2001 to commercialize biomass pyrolysis technology. ROI's patent pending process uses a specially designed, indirectly heated auger. Proposed advantages are that the process does not require and inert gas stream to fluidize a bed or transport hot sand. Elimination of the recycle blower and the associated heat load is reported to greatly reduce the capital and operating costs for the ROI process.

ROI's business approach is to develop a low cost, transportable reactor to be located in areas where there are limited feedstocks and/or integrated into operations with limited

[67] Renewable Oil International web site, www. renewableoil.com
[68] Renewable Oil International 2002.

waste biomass for feedstock, but sufficient to produce enough bio-oil for process heat and electricity generation. To date emphasis has been on agricultural waste as a feedstock. A demo facility has been constructed using chicken liter as a feedstock.

In 2003, ROI received a $499,000 grant from Renewable Energy Trust[69], a division of the Massachusetts Technology Collaborative, to construct and demonstrate a 15-dry-tons-per day Advanced Fast Pyrolysis Biorefinery Plant at Berkshire Hardwoods. Berkshire Hardwoods is a sawmill located in Chesterfield, Massachusetts. Under the agreement, ROI will establish a Massachusetts company, ROI Massachusetts Operations, LLC. The project will use ROI's pyrolysis technology to convert woody biomass into Bio-oil. The bio-oil produced will be tested in internal combustion engines and a combustion turbine. Based on the successful demonstration tests, the plant will continue to operate at the sawmill as a combined heat and power system while further reviews will be completed to determine the feasibility to construct a 125-dry-ton-per-day plant at the site. This project has the support of the MA Department of Conservation and Recreation as this technology can make use of clean wood waste, thereby reducing the demand on landfills. In speaking with the Project Manager for the Clean Energy Program, in August, 2005, it was stated that the transportable reactor being built in Ottawa, Canada, was 80-90% complete. However, they were having difficulty obtaining the required permits from the local community and that the demonstration plant may need to be relocated to a different location.

Renewable Oil International, LLC requested that the Massachusetts Division of Energy Resources (DOER) provide and Advisory Ruling with regard to the qualification for the Massachusetts Renewable Energy Portfolio Standard (RPS) of the proposed new Bio-oil project. An advisory ruling was issued on March 9, 2004.[70] In this request ROI proposed to design, fabricate, install and operate a fast pyrolysis unit at a sawmill in western Massachusetts. That unit will extract bio-oil from a feedstock of sawmill debris. The bio-oil will be transported to the facilities of Advanced Engine Technologies (AET) for testing with engine in its laboratories. Based on those tests it will be determined what modifications will be necessary to convert engines to operate on straight bio-oil fuels. A 60-hp rotary engine/generator modified for operation on straight bio-oil fuels will then be installed at the project site and tested. In its Advisory Ruling, DOER found the bio-oil project proposed by ROI to fall within the eligibility criteria for new renewable generation biomass units as described in the RPS regulations at 14.05(1)(a)6. DOER also stated that if the proposed equipment receives valid air permit(s) from the Massachusetts DEP, the project would thereby qualify as using low emission technology.

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[69] Renewable Energy Trust web site, www.masstech.org/Project _lst_rslt.asp?ID=53

[70] Commonwealth of Massachusetts Office of Consumer Affairs & Business Regulation, Division of Energy Resources. *Advisory Ruling for Renewable Oil International, LLC's Proposed BioOil Project, March 9, 2004.*

6. Market Analysis

6.1 Bio-oil as a Heating Oil [71]

In the eleven states composing the Northeast Regional Biomass Program (NRBP)[72] the amount of energy used for heating oil from residential, commercial and institutional uses is approximately 1.24 times greater than the amount of diesel fuel used for transportation in the region (i.e., 869 trillion Btu vs. 698 trillion Btu). From an energy security perspective, i.e. independence from petroleum, the source of heating oil is of prime importance.

In June 2005, the average wholesale price of No.2 Heating Oil in the northeast was $1.69 per gallon; $1.80 per gallon for commercial/institutional users; and $1.91 per gallon for residential users (Table 5.)[73,74]. The equivalent price for bio-oil on an energy equivalent basis would be $0.91, $0.97 and $1.03 respectively. The average, current price for green, whole tree wood chips is $26 per ton.[75] At wholesale prices that leaves a net margin of $66.07 for all operating costs after payment for feedstock. For No.6 residual oil, a more likely, near-term market for bio-oil for reasons to be discussed later, the margin is even less; $35.57.[76] These margins are not sufficient to warrant construction of a bio-oil plant

	Sales to End Users						Sales for Resale (wholesale) (C/gal)
Geographic Area	Residential Consumers[a] (C/gal)	Commercial/ Institutional Consumers[a] (C/gal)	Industrial Consumers[a] (C/gal)	Through Retail Outlets[b] (C/gal)	Other End Users[c] (C/gal)	Average (C/gal)	
US	198.3	171.8	171.7	181.2	181.4	177.6	167.2
PAD 1A	197.6	178.3	176.2	191.7	169.6	187.4	165.1
NH	190.9	179.9	183.0	192.1	165.3	187.8	169.1

[a] Sales of No.2 fuel oil
[b] Includes sales of diesel fuel
[c] Includes sales to agricultural customers or utilities

Table 5. No.2 Distillate Prices by Sales Type and State – Average Prices for June 2005 (cents per gallon, excluding taxes)[77]

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[71] Easterly, James L. *Assessment of Bio-Oil as a Replacement for Heating Oil.* Prepared for Northeast Regional Biomass Program Managed by the CONEG Policy Research Center, Inc. November 2002.
[72] Northeast Regional Biomass Program. www.nrbp.org
[73] U.S. Energy Information Administration. www.eia.doe.gov
[74] Prices for petroleum based products are based on prices as of the end of June 2005. Since prices for petroleum based products are changing daily, the reader may need to adjust to current prices and modify conclusions accordingly.
[75] Private Conversation, Doug York, Whitefield Power & Light Co. August 2005.
[76] U.S. Energy Information Administration. June 2005
[77] Ibid

	No.2 Heating Oil			Bio-oil				
Fuel Oil Market	Btu/gal	Ave NE Price $/gal	$/MMBtu	Btu/gal	Market Value $/gal	Yield BioOil gal/dry ton[b]	Revenue Dry Wood $/ton	Revenue[a] Green Wood $/ton
Wholesale	138,690	$1.69	$12.17	75,000	$0.91	132	$120.12	$66.07
Industrial	138,690	$1.83	$13.18	75,000	$0.99	132	$130.68	$71.87
Commercial/Institutional	138,690	$1.80	$12.96	75,000	$0.97	132	$128.04	$70.42
Residential (delivered)	138,690	$1.91	$13.75	75,000	$1.03	132	$135.96	$74.78

[a] Assuming green wood has an average moisture content of 45%
[b] Assuming 66% conversion into bio-oil

Table 6. No.2 Heating Oil Prices for Different End Users vs. Bio-oil Values[78] - Average Prices for June 2005 ($/gal excluding taxes)

	No.6 Residual Oil			Bio-oil				
Fuel Oil Market	Btu/gal	Ave NE Price $/gal	$/MMBtu	Btu/gal	Market Value $/gal	Yield BioOil gal/dry ton[b]	Revenue Dry Wood $/ton	Revenue[a] Green Wood $/ton
Wholesale	153,200	$1.01	$7.72	75,000	$0.49	132	$64.68	$35.57
End User	153,200	$0.90	$6.48	75,000	$0.44	132	$58.08	$31.94

[a] Assuming green wood has an average moisture content of 45%
[b] Assuming 66% conversion into bio-oil

Table 7. No.6 Residual Oil Prices for Different End Users vs. Bio-oil Values[79] - Average Prices for June 2005 ($/gal excluding taxes)

producing and selling only bio-oil. To be economically viable the plant would need to produce and sell additional higher value added products and/or warrant policies and incentives from state and federal governments in support of bio-oil, similar to what is currently being done for other biomass fuels such as ethanol.[80]

[78] Ibid
[79] Ibid

By comparison, ethanol with energy content similar to bio-oil (84,000 Btu/gal vs. 75,000 Btu/gal) currently sells at approximately $27.00 [81] per million Btu's as compared to the wholesale price for No.2 Heating oil of $12.11 and that for bio-oil of $21.56 [82] per million Btu's. Subsidies for ethanol and other renewable energy sources are based on benefits they provide to the U.S. in terms of increased energy security, i.e. reduced dependencies on petroleum imports.

6.1.1 Residential Applications

It is unlikely that any near-term market for residential use of bio-oil will emerge. Barriers to entering the residential heating oil market include: lower energy content of the fuel, its viscosity which is higher than No.2 fuel oil, its acidity, its high moisture content, and storage characteristics. Additional testing is required to assess bio-oil performance in existing residential furnaces, as well as the need to demonstrate the stability/storage characteristics over time.

To convert to bio-oil residences will probably need new fuel storage tanks and delivery systems to accommodate the higher viscosity and acidity. Customers must also be willing to pay a premium for renewable, "green" heating oil. In the current market place this seems unlikely without state and/or federal intervention.

6.1.2 Commercial Institutional Applications

Commercial and institutional applications appear to be a more near-term market for bio-oil. A single building and/or complex could provide a significant market for a regional plant. Many commercial and/or industrial applications currently burn No.6 fuel oil, which has a higher viscosity and storage stability similar to bio-oil, thus requiring less intensive changes to their storage and delivery systems. Such customers are also more likely to have an incentive (economic and environmental) to pay a premium for renewable, "green" fuel in that the burning of bio-oil produces lower emissions of NO_x and SO_x while being CO_2 neutral. There are also several alternative strategies that can be pursued for burning bio-oil as a fuel. These include 100% usage of bio-oil as a boiler fuel, co-injection of bio-oil into a boiler via a dedicated fuel port, or blending bio-oil with other liquid fuels using techniques such as the BDM™ process.[83,84,85]. There are circumstances whereby institutional buildings would provide an attractive market

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[80] Present law provides for a partial federal excise tax exemption of 51 cents per gallon for ethanol blended into gasoline. The Volumetric Ethanol Excise Tax Credit (VEETC) legislation passed in 2004 extends this tax credit through 2010. see web page www.ncga.com/ethanol/main/economics.htm

[81] This is based on the July 29, 2005, ethanol price of $2.05 /gal. see web page www.zfacts.com/p/60.html

[82] This assumes a bio-oil plant operating profitably with a 20% return on investment for its investors. See Section 7 of this report.

[83] CANMET Energy Technology Center. www.cetc-cetc.gc.ca

[84] Sturzl 1997.

[85] Ensyn Technologies, Inc 1995.

opportunity for a renewable, "green" fuel such as bio-oil. Such opportunities are as follows.

Required Renewable Energy Use in Federal Buildings. Federal agencies and buildings they occupy have a mandate to increase their use of renewable energy. Executive Order 13123 requires federal agencies to increase their use of renewable electricity to 2.5% of their supplies by 2005.

State Requirements for Renewable Energy Use. New York State has Executive Order No. 111 directing state agencies to be more energy efficient and environmentally aware. This order requires state agencies obtain 10% of their electricity from renewable sources by 2005 and 20% by 2010. New Hampshire does not have any similar requirement.

Regional Initiatives to Reduce Greenhouse Gas Emissions. The New England Governors' Conference and the Eastern Canadian Premiers adopted a Climate Change Plan aimed at reducing emissions of greenhouse gas in the Northeast region (New England Governors Conference, 2002). Although there is no mandated requirement for individual states, burning of bio-oil, a renewable biomass feedstock would lower greenhouse gas emissions by replacing fossil-based petroleum fuels.

Federal "Biomass and Alternate Methane Fuels Super ESPC" Program. This program should be considered as a possible means for promoting bio-oil as an alternative biomass fuel.

6.2 Electric Power Generation

A bio-oil facility operating in New Hampshire would have the opportunity to sell electricity in the region's wholesale market. The following discussion considers this market, the possibility that a premium could be realized through the sale of both electricity and renewable energy certificates, and other energy issues important for a bio-oil facility developer to consider.

6.2.1 Wholesale Electricity Markets in New Hampshire

New Hampshire electricity markets are part of the broader ISO-New England (ISO-NE) market, which serves the six New England States – Connecticut, Rhode Island, Massachusetts, Vermont, Maine and New Hampshire. Formed to manage a restructured and competitive market for wholesale electricity, duties of the ISO include providing independent, open and fair access to the region's transmission system", and "facilitating market-based wholesale electric rates."[86]

Any generation facility seeking to sell electricity at the wholesale level would need to

[86] ISO New England website, www.isone.org

interconnect with the electricity transmission and distribution system, often referred to as the "grid", and sell electricity through the ISO New England system. It would be possible to sell electricity directly to a neighboring facility or facilities without accessing the electricity grid-- and therefore not going through the ISO system -- but this approach has limitations.

Throughout this effort to evaluate the feasibility of locating a bio-oil facility in New Hampshire, there has been considerable discussion of locating a bio-oil production facility at the Whitefield Industrial Park in Whitefield, NH. One reason for this interest has been the presence of Whitefield Power & Light Company, a wood-fired power plant. This facility, with historic contracted generation of 13.8 MW, recently accepted a buyout of its PURPA rate order[87], and operated under an agreement with the New Hampshire Timberland Owners Association that expired in the summer of 2003.[88]

Whitefield Power & Light has a connection to the New England electricity grid, and it may be possible for a bio-oil production company facility to co-locate with the facility and negotiate use of the grid connection. There are also non-operating wood-fired power plants in Bethlehem, Barnstead and Alexandria that may be possible sites for electricity generation using bio-oil. As a result of previous buyout agreements, some of these sites may have restrictions on their ability to generate power for the wholesale market.[89]

ISO New England publishes a wealth of historic data on wholesale electricity transactions in the region. One of the most useful historical pieces of information is the monthly average clearing price, which provides the average wholesale price paid for electricity in each month. While wholesale electricity prices vary widely from day-to-day and hour-to-hour, the monthly average clearing price provides a fair historical perspective of historic market activity. Since January 2002, wholesale electricity prices have ranged from a low of $25.17/MWH ($0.025/kwh) in February 2002 to a high of $69.42/MWH ($0.069/kwh) in February 2003. ISO New England is currently not reporting monthly average clearing prices more recent than February 2003. However, daily and hourly clearing prices are reported for recent dates. On September 4, 2005, the clearing prices ranged from a low of 12.6 $/MWh to a high of 41.61 $/MWh with a daily average of $27.46 /MWh (Table 8).

6.2.2 Regional Markets for Renewable Power

In addition to selling electricity into the wholesale market, a bio-oil producer could potentially receive a premium for electricity generated using a renewable fuel. According to the *Database of State Incentives for Renewable Energy*, thirteen states have enacted renewable portfolio standards.[90] Three states in New England – Connecticut,

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[87] New Hampshire Public Utilities Commission Order No. 23,840. November 9, 2001.
[88] Stock, Jasen. Letter of the New Hampshire Timberland Owners Association to the NH Public Utilities Commission, Docket No. DE 01-089. September 23, 2002.
[89] Innovative Natural Resource Solutions LLC 2002.
[90] www.dsireusa.org

Massachusetts and Maine – have "renewable portfolio standards" (RPS), which essentially mandate that any supplier of electricity operating in the state must derive a certain portion of that electricity from renewable sources. Each state defines what qualifies as "renewable" for purposes of their portfolio standard, so that generation that qualifies in one state does necessarily qualify in other states. Generation based in New Hampshire can sell its renewable energy certificates (RECs) to customers in any state in the NEPOOL region (New Hampshire, Vermont, Maine, Massachusetts, Connecticut, and Rhode Island), and in some circumstances may be able to sell RECs outside of this region as well.

Year	Month	$/MWh	Day	Hour	$/MWh
2001	January	$ 62.74	8/4/2005	1	$ 20.64
2001	February	43.07		2	13.86
2001	March	50.18		3	13.00
2001	April	38.84		4	12.60
2001	May	43.59		5	12.02
2001	June	37.33		6	24.76
2001	July	52.66		7	21.54
2001	August	43.52		8	29.10
2001	September	33.82		9	30.02
2001	October	31.07		10	34.29
2001	November	27.57		11	33.71
2001	December	27.22		12	32.00
				13	32.00
2002	January	26.31		14	32.00
2002	February	25.17		15	32.00
2002	March	31.18		16	32.00
2002	April	30.71		17	32.00
2002	May	34.43		18	32.00
2002	June	30.08		19	32.00
2002	July	34.52		20	28.41
2002	August	46.43		21	33.40
2002	September	41.17		22	41.61
2002	October	43.11		23	29.71
2002	November	39.79		24	24.39
2002	December	46.35			
			Daily	Ave	27.46
2003	January	60.18			
2003	February	69.42			

Table 8. Monthly Average Electricity Clearing Price, New England and Daily Hourly Clearing Price New England, August 4, 2005. [91]

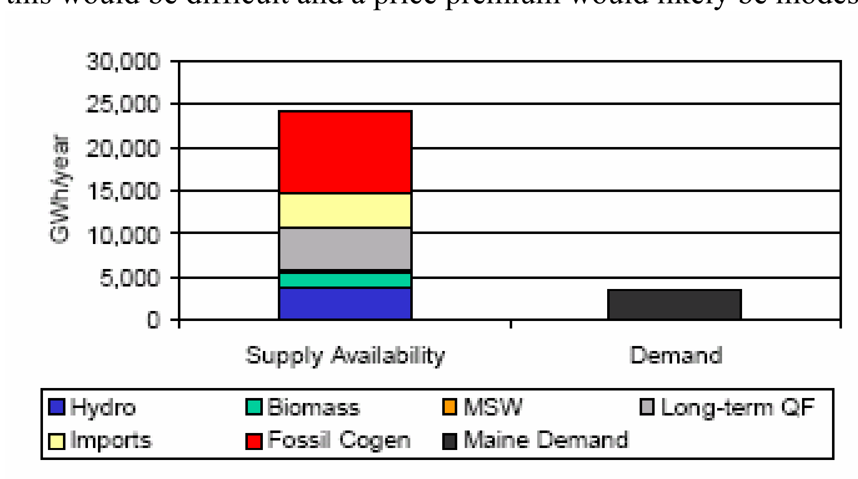
[91] ISO New England website, www.isone.org. ISO New England is not reporting more recent data on a monthly basis at their website.

6.2.2.1 New Hampshire

New Hampshire does not presently have a renewable portfolio standard. The New Hampshire General Court has considered establishment of such a standard on at least two occasions, and to date has chosen to address renewable energy issues through other policies. The *New Hampshire Energy Plan*, released in November 2002, recommends establishment of an RPS[92], but this has not occurred. In 2004, a bill creating an Energy Planning Advisory Board, to maintain and implement the NH Energy Plan was passed and signed by Governor Benson. Recommendations of this Board are not yet available.

6.2.2.2 Maine

Maine has a renewable portfolio standard that requires that 30% of the electricity sold by suppliers come from either renewable generation or "efficient resources" – the highest such standard in the nation.[93] However, prior to establishment of an RPS, Maine derived roughly 45% of its power from renewable resources, primarily biomass and hydroelectric. Maine's RPS allows a great deal of generation that does not qualify for participation in the renewable portfolios of some other states. According to industry sources, the supply of electricity eligible to participate in Maine's RPS is eight times the demand.[94] If an electric generating facility using bio-oil produced electricity at low costs when compared to other renewable generation, it is possible that Maine's RPS may provide a market. However, because of the existing overcapacity of renewable generation, this would be difficult and a price premium would likely be modest, if it existed.



Data Source: Independent Energy Producers of Maine

Figure 8. Comparison of Eligible Supply and Demand, Maine RPS

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92 Governor's Office of Energy & Community Services 2002.
93 Ibid
94 Turkel, Tux. "Renewable Energy Back on Front Burner." *Maine Sunday Telegram.* April 6, 2003.

Maine is currently reviewing its programs to encourage renewable energy, including its Renewable Portfolio Standard.[95] Changes to the Maine RPS could make this a more attractive opportunity for participation by a bio-oil facility, and should be reviewed again if a facility is closer to construction.

6.2.2.3 Massachusetts

Massachusetts has a renewable portfolio standard that requires 1.5% of electricity be procured from eligible providers in 2004, with the percentage required climbing annually until at least 2009, when 4% renewable power will be required. However, the Massachusetts RPS has a number of eligibility criteria that may restrict participation by a generator using bio-oil. These rules would apply to any electric supplier wishing to access Massachusetts's RPS market.

> **Eligible Biomass Fuel**: Bio-oil is an eligible fuel source, as the definition of biomass fuel includes "neat liquid fuels that are derived from" sources such as "brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that are not mixed with other solid waste."[96]
>
> **New Renewable Generation Unit**: If a bio-oil production facility developed a new electricity generating facility, where bio-oil was used to generate electricity, it is anticipated that this would qualify under the Massachusetts RPS. The rules call for "low-emission, advanced biomass power conversion technologies"[97] using an eligible biomass fuel. Renewable Oil International, LLC requested that the Massachusetts Division of Energy Resources (DOER) provide and Advisory Ruling with regard to the qualification for the Massachusetts Renewable Energy Portfolio Standard (RPS) of the proposed new Bio-oil project. An advisory ruling was issued on March 9, 2004.[98] In its Advisory Ruling, DOER found the bio-oil project proposed by ROI to fall within the eligibility criteria for new renewable generation biomass units as described in the RPS regulations at 14.05(1)(a)6. DOER also stated that if the proposed equipment receives valid air permit(s) from the Massachusetts DEP, the project would thereby qualify as using low emission technology.
>
> **Use of an Existing Wood-fired Facility:** New Hampshire's eight existing wood-fired power plants are not eligible for the Massachusetts RPS. The RPS rules specifically state that "pile burn, stoker combustion or similar technologies shall not constitute an advanced biomass

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[95] Maine Public Utilities Commission. *DRAFT Report and Recommendations on the Promotion of* Renewable Resources. 2003.

[96] 225 CMR 14.02: Definitions - Renewable Portfolio Standard

[97] 225 CMR 14.05 (1)(a)6.a: Eligibility Criteria for New Renewable Generation Units – Renewable Portfolio Standard

[98] Commonwealth of Massachusetts Office of Consumer Affairs & Business Regulation *2004.*

conversion technology".[99] However, it may be possible to re-power an existing biomass facility -- such as the facility in Whitefield or other now closed facilities in Barnstead, Alexandria or Hopkinton – as a bio-oil facility and qualify for the Massachusetts RPS.

In April 2004, the Massachusetts Division of Energy Resources issued a guideline that makes it clear that existing wood-fired facilities that re-tool with "advanced" biomass generation (including bio-oil, subject to emissions criteria) are eligible for full participation in the state's RPS.[100] Given this ruling, it may be advantageous, where possible, to use the existing interconnection and other facilities of an established wood-fired power plant to manufacture and combust bio-oil.

Co-firing at an Existing Facility: For purposes of the Massachusetts RPS, co-firing refers to supplementing RPS-eligible renewable fuels – in this case bio-oil – along with RPS ineligible fuels, such as coal. Co-firing has seen increasing interest from utilities nationwide in order to help control certain emissions, meet environmental fuels requirements, or stabilize fuel price.[101] If bio-oil was co-fired with coal, as has been tested in other states[102], the percentage of generation derived from bio-oil might be eligible for the Massachusetts RPS, if the generation technology met RPS standards [103]. However, it is critical to note that facilities co-firing biomass fuels (including bio-oil) with coal are required to meet strict emissions criteria: "If using an Eligible Biomass Fuel, the entire Generation Unit must meet the requirements of a low emission, advanced biomass power conversion technology."[104] This requirement may make co-firing a practical impossibility from an RPS perspective.

Price Premium for Renewable Generation in Massachusetts: Massachusetts uses tradable certificates to assure compliance with its RPS. The certificates are traded separately from the energy, and provide additional revenue for generators of renewable electricity. According to forecasts developed for the Massachusetts DOER, the "base case" (anticipated situation) forecast shows certificates trading in the neighborhood of $25/MWH, or 2.5¢/kWh through 2012.[105] High- and low-priced scenarios show certificates valued at as little as $1/MWH to as

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[99] 225 CMR 14.05 (1)(a)6

[100] Massachusetts Division of Energy Resources. *Guideline on the MA RPS Eligibility of Generation Units* that Re-tool with Low Emission, Advanced Biomass Technology. April 16, 2004.

[101] Innovative Natural Resource Solutions LLC and Draper / Lennon, Inc. *Use of Low-Grade and Underutilized Wood Resources in New Hampshire*. Prepared for the NH Department of Resources & Economic Development. January 2001.

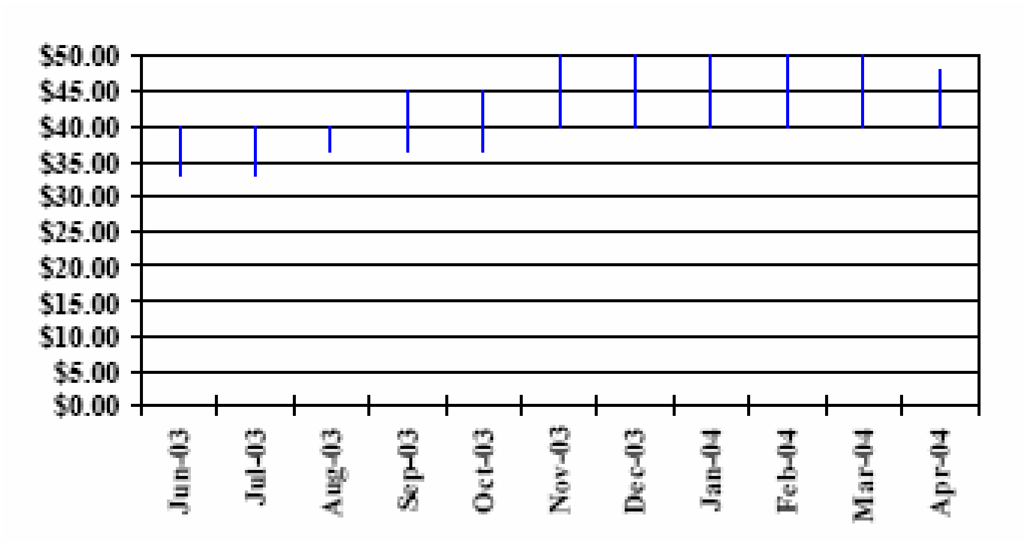
[102] Struzl 1997

[103] 225 CMR 14.05 (3)(a): Co-firing With Ineligible Fuels Waiver – Renewable Portfolio Standard.

[104] 225 CMR 14.05 (3)(b)

[105] Grace, Robert C. (of Sustainable Energy Advantage) and Karlynn S. Cory (of LaCapra Associates). Massachusetts RPS: 2002 Cost Analysis Update – Sensitivity Analysis. December 16, 2002.

much as $45/MWH. (It should be noted that this analysis was complete prior to the significant changes to Connecticut's RPS, which occurred in June 2003. It is likely that the increased demand from Connecticut for RECs will push prices higher.) The analysis also notes that there may be significant short-term volatility in certificate prices; the forecast is intended to capture general market conditions. Current market data show that these certificates traded for $38.00/MWH for 2003, and forward trading for 2005 has certificates valued between $40.00 and $50.00 MWH.[106] These certificate prices, when combined with revenues from electricity sales and other products, could help make a bio-oil facility in New Hampshire economically viable.



Data Source: Evolution Markets LLC Monthly Market Update, Compliance REC Markets

Figure 9. 2005 Massachusetts Renewable Energy Prices

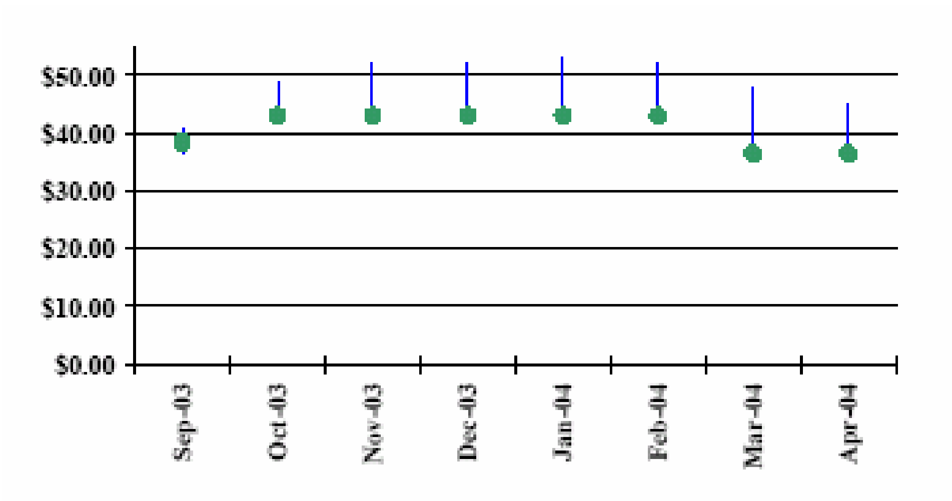
6.2.2.4 Connecticut

Connecticut has a renewable portfolio standard that calls for 6% of electricity sold in the competitive marketplace to come from renewable generation in 2000; this increases to 13% by 2009. Connecticut has two classes of renewables; generation from "new, sustainable biomass" - a category for which a new bio-oil facility may qualify - receives preference over some other types of renewable power. In the 2003 legislative session, Connecticut changed its RPS to mandate participation by most electricity providers in the state.[107] This legislation clarified the rules for participating in the Connecticut RPS, including:

• For a Class One facility (the preferred category, which also includes solar,

[106] 79 Evolution Markets LLC. Monthly Markets Update, REC Markets. March 2004.
[107] Connecticut General Assembly Senate Bill No. 733. 2003.

wind, landfill gas and fuel cells), biomass must be harvested "in a sustainable manner";
• For a Class One facility, emissions of NOx must be equal to or less than .075 pounds per million BTU of heat input;
• Changes the percentage of renewables (from both Class One and Class Two categories) required each year, but also requires utilities to provide renewable power as a component of their "transition service", thus expanding the number of customers who will purchase renewable power;
• Allows purchase of renewable power from New England and New York, and allows purchase from some Mid-Atlantic states if they adopt an RPS similar to Connecticut's.
In early trading, Connecticut Class One certificates are trading between $36.50 and $45.00 / MWH for 2005[108]. Class Two certificates, which include biomass facilities that do not meet the Class One standards, are trading at a nominal amount, with prices ranging from $0.25 to $1.00/MWH.[109]



Data Source: Evolution Markets LLC Monthly Market Update, Compliance REC Markets

Figure 10. 2005 Connecticut Class 1 Renewable Energy Prices

It should be noted that the definition of renewable power in Connecticut does not directly address liquid fuels derived from biomass, but such a facility would presumably be treated as a biomass facility, and subject to the RPS eligibility requirements for biomass generating facilities. If a bio-oil facility were closer to development, it would be advisable for the developer to request a formal advisory ruling on this matter from the Connecticut Department of Public Utility Control.

[108] Evolution Markets LLC. Monthly Markets Update, REC Markets. November 2003.
[109] Evolution Markets LLC. Monthly Markets Update, REC Markets. July 2003.

6.2.2.5 Rhode Island Renewable Portfolio Standard

In June, 2004, Rhode Island established a renewable portfolio standard.[110] This RPS begins in 2007, and increases annually until 2019. It contains provisions for both new and existing renewable generation.

Eligible Biomass Facility: To qualify as "new" for purposes of the Rhode Island RPS, a biomass facility must have begun operation (or have incremental new renewable output derived through capital investment) after 1997, use "eligible biomass fuels and [maintain] compliance with current air permits".[111] Eligible biomass means "fuel sources including brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that is not mixed with other solid wastes… or neat bio-diesel and other neat liquid fuels that are derived from such fuel sources."[112]

Price Premium. As the Rhode Island RPS has just been established, there is no pricing available at this time. There is a price cap of $50.00 per REC (2003 dollars), which will be adjusted annually for inflation.

Year	Existing	New
2007	2.0%	1.0%
2008	2.0%	1.5%
2009	2.0%	2.0%
2010	2.0%	2.5%
2011	2.0%	3.5%
2012	2.0%	4.5%
2013	2.0%	5.5%
2014	2.0%	6.5%
2015	2.0%	8.0%
2016	2.0%	9.5%
2017	2.0%	11.0%
2018	2.0%	12.5%
2019	2.0%	14.0%

Table 9. Rhode Island RPS Requirements

110 State of Rhode Island General Assembly. S. 2082. An Act Relating to Public Utilities and Carriers – Renewable Energy Standard. June 29, 2004.
111 State of Rhode Island General Assembly. *S. 2082. An Act Relating to Public Utilities and Carriers –* Renewable Energy Standard. June 29, 2004.
112 Ibid

6.2.2.6 Overall Demand for Compliance RECs in New England

Publicly available information suggests that demand for RECs in Massachusetts and Connecticut will outpace supply the coming years. In public testimony[113], New Hampshire PUC staff analysis indicated that REC demand in Massachusetts and Connecticut is expected to exceed supply for the years 2003 – 2010. This analysis assumed that Cape Wind, a proposed 420 MW offshore wind farm, and Schiller Station's proposed biomass program both came on line for 2006, and that no other new facilities entered this market. New participants in the REC market, or changes in existing and proposed renewable energy facilities, could alter this analysis.

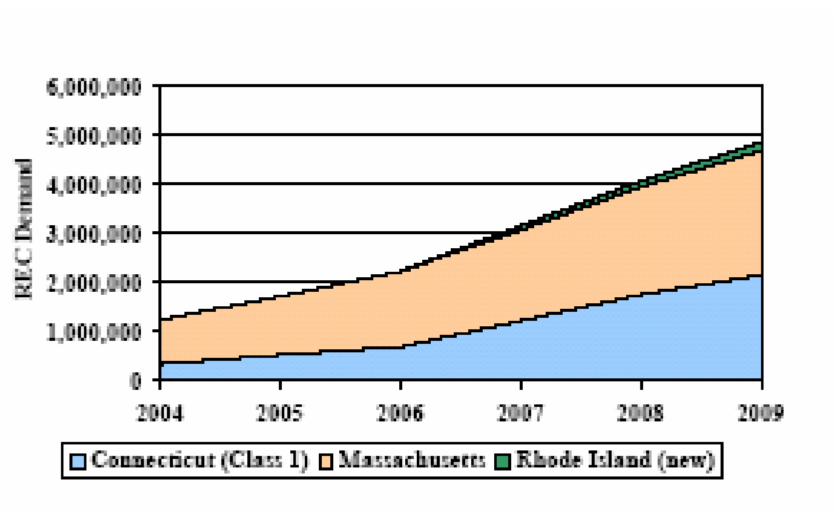


Figure 11. Anticipated New England High-Value REC Demand 2004 - 2009

6.2.3 Carbon Credits

There has been significant interest from stakeholders in the possibility of raising revenue through the sale of "carbon credits". In many policy discussions, energy derived from sustainably harvested biomass is considered "carbon neutral" – the emissions of carbon are offset by carbon sequestered by forest growth.[114] Carbon is emitted from the combustion of wood to generate power – an estimated 42.8 pounds of carbon for each 100 pounds of dry wood burned – but an equal amount of carbon is sequestered over a 60 to 100 year re-growth period.[115] It should be noted that not all regulatory frameworks recognize biomass as "carbon neutral". For example, as part of their electricity generation emissions reporting to consumers, energy suppliers in Massachusetts are

[113] NH PUC Docket DE-03-166
[114] Innovative Natural Resource Solutions 2002.
[115] Maine State Planning Office and University of Maine. *State of Maine Climate Change Action Plan*. 2000.

required to report actual "smokestack" carbon emissions from biomass plants, and not count future carbon sequestration associated with sustainable forest management.[116]

Because of its "carbon neutral" emissions profile, there has been significant interest from proponents of biomass energy to participate in carbon offset markets – in effect deriving revenue from the carbon not emitted. At this writing, carbon offset markets in the United States are in the formative stages, and the revenue associated with carbon offsets is modest. Nationally, carbon offsets can presently be sold for between $1.00 and $2.00 per ton, and these transactions are generally used to satisfy voluntary reductions or are speculative transactions.[117] The Oregon-based Climate Trust has solicited carbon reductions for as high as $6.00 per ton, but projects are generally funded at a lower level.[118]

However, it is highly unlikely that trading carbon credits would be in the economic interest of a bio-oil facility. This is because it is generally accepted that energy producers must choose to participate in either the carbon market or the renewable energy credit market, but cannot participate in both. When a renewable energy producer sells a green credit, they sell all of the non-price attributes associated with the generation – "including but not limited to the unit's fuel type, emissions, vintage and RPS eligibility."[119]
The sale of a renewable energy certificate, combined with the sale of carbon credits, is referred to as "partial double sale". In this instance, the purchaser of the renewable energy certificate reasonably expects to own and control all generation attributes, but one attribute – carbon emissions – is sold to another party. While each state addresses this issue separately, the Green Electricity Marketing Guidelines prepared by the National Association of Attorneys General discourage this practice.[120]

Because the attribute associated with carbon- neutral generation - emissions – is sold as part of participation in a renewable portfolio standard, it is likely that the separate sale of carbon credits is not permitted. For example, participants in the Massachusetts RPS are required to assure that "New Renewable Generation Attributes have not otherwise been, nor will be, sold, retired, claimed or represented as part of electrical energy output or sales, or used to satisfy obligations in jurisdictions other than Massachusetts."[121]

6.3 Refined Chemicals

Although the original interest in the fast pyrolysis of biomass was the production of alternative fuels, the interest has broadened to include the bio-refinery concept in which

[116] Communication with Susan Weber, Massachusetts Department of Environmental Protection. April 14, 2003.
[117] Communication with Mark Trexler, Trexler and Associates. August 19, 2003.
[118] Personal meeting with Sean Clark, The Climate Trust, March 23, 2004.
[119] 225 CMR 14.02: Definitions – Renewable Portfolio Standard
[120] Holt, Ed. "Renewable Energy Certificates and Generation Attributes." *Regulatory Assistance Project* Issuesletter. May 2003.
[121] 225 CMR 14.09: Compliance Filings for Retail Electricity Suppliers

higher value products are extracted from bio-oil. The revenue generated by the sale of the extracted chemicals becomes a significant factor when evaluating the economic viability of a bio-oil facility. As discussed in later sections, it is apparent that a stand alone facility relying only on the lower value applications is not economically viable. For a bio-oil facility to operate profitably it must rely on the revenue stream from other higher value products such as those generated using the bio-refinery concept.

There have been numerous studies and papers written on the chemical composition of bio-oil. An informative summary of earlier studies was written by Radlein.[122] Table 10 presents the range of abundance for the various classes of compounds found in bio-oil produced from the pyrolysis of wood.[123]

Compound Class	Composition Range (Wt % of Organic Fraction of Bio-oil)
C_1 Compounds (formic acid, methanol and formaldehyde	5-10
$C_2 – C_4$ linear hydroxyl and oxo substituted aldehydes and ketones	15-35
Hydroxyl, hydroxymethyl and/or oxo substituted furans, furanones and pyranones	10-20
Anhydrosugars including Anhydro-oligosaccharides	6-10
Water soluble carbohydrate derived oligomeric and polymeric material	5-10
Monomeric methoxyl substituted phenols	6-15
Phenolic Lignin	15-30

Table 10. Compound Classes in Bio-oil [124]

Specific chemicals having an abundance greater than one percent by weight (wt %) include formic acid / formaldehyde (0-8.9), hydroxyacetaldehyde (9.6-10.8), acetic acid (3.7-4.8), diacetyl (0-1.1), glyoxal (1.4-3.1), acetol (1.5-2.8), levoglucosan (2.3-4.9), cellobiosan (1.2-3.0), and pyrolytic lignin (24.2-28.3).

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122 Radlein, D. "The Production of Chemicals From Fast Pyrolysis of Bio-oils" in *Fast Pyrolysis of Biomass: A Handbook*, edited by Bridgewater, A. et.al. (CPL Scientific Publishing Services Limited, Newbury, 1999), pp.164-188.

123 Composition is sensitive to they type of wood being used, i.e. softwood, hardwood, mixture, etc.

124 Radlein, D. 1999

As stated by Radlein and subsequent studies, it is easy to envision a bio-refinery concept such as that shown in Figure 12 which in theory could produce a variety of higher value added products. To date little progress has been made towards the development of a commercially viable bio-refinery and/or the extraction of specific chemical components.

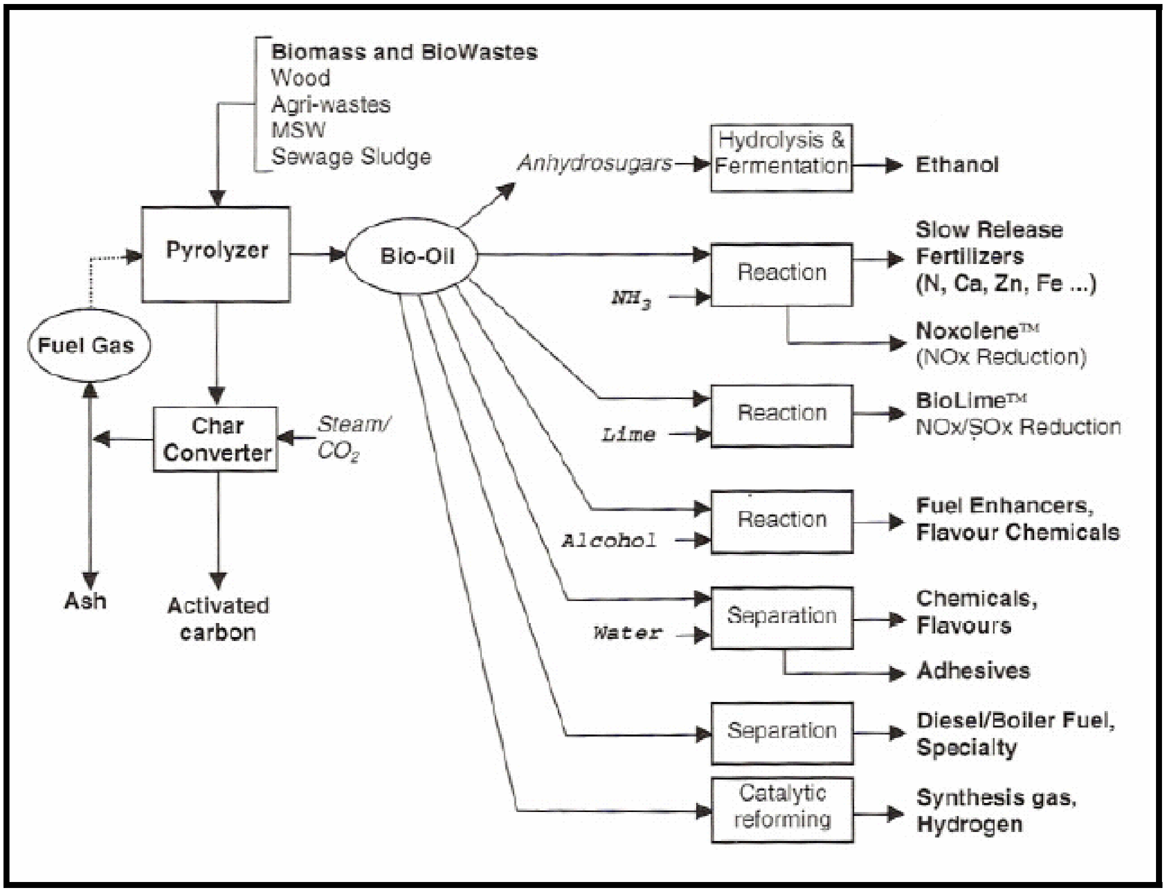

Figure 12. Concept of Bio-oil Refinery [125]

One reason for this is the thermal and chemical instability of bio-oil which precludes the use of conventional distillation processes for separating bio-oil into useful classes of chemicals. The alternative method for separation is the use of solvents; the most common being water.

Aqueous extracts of bio-oil have been found to be an excellent source of smoke flavors and browning agents used in the food industry. In fact, these are the only bio-oil derived chemicals currently being produced and sold commercially. Red Arrow Products Company of Manitowoc, Wisconsin manufactures a range of food flavorings and other additives including a liquid smoke product which are derived from bio-oil produced by the fast pyrolysis of specific hardwood species.[126] Red Arrow is believed to have an

[125] Ibid
[126] Available at www.redarrowusa.com

exclusive agreement with Ensyn to use its patented RTP™ technology for the production of bio-oil for the production of food additives. Since it is unlikely that Red Arrow would expand their operations into New Hampshire, the pursuit of the food additives market will not be considered for the purposes of this report.

The easiest component of bio-oil to be separated by water extraction is pyrolytic lignin (PL). The unfractionated PL has been studied as a replacement for phenol in the production of phenol-formaldehyde (PF) resins used as an adhesive in the wood products industry. Studies by Kreibich[127] and later studies by Ensyn[128] have shown that unfractionated PL can successfully replace 40-50 of the phenol used in the production of phenol-formaldehyde resin used in the production of plywood, OSB and other laminated wood products. PF resins are produced from phenol, formaldehyde, sodium hydroxide and water, with phenol being approximately 37 % by weight.

Phenol is produced by the peroxidation of cumene (isopropylbenzene) which is derived from two petrochemical feedstocks, benzene and propylene. As a result, price and availability of phenol are strongly dependent on crude oil prices and on petroleum refinery capacities. From 1996 to 2003 the U.S. market for phenol was relatively constant at approximately 4.5 billion pounds per year with an average price of $0.35 per pound (high $0.406 and low $0.307).[129,130,131] Of the U.S. market, 28% or 1.26 billion pounds are used in the production of PF resins representing a total annual market value of phenol used in the U.S. for the manufacture of PF resins of approximately $440 million. The stagnant market and weak margins caused several U.S. plants to close during this period, the most notable being a 500,000 tons/year Chevron Phillips plant in Port Arthur, Texas. The major producers (billions lbs/yr) in the U.S. are Sunoco (2.04), Shell (1.18), Mt. Vernon Phenol Partnership (0.71), INEOS Phenol (0.88) Dow (0.65) and Georgia Golf (0.66).

In 2004 the North American demand for phenol increased approximately 17% over the previous year with projected worldwide demand to grow from 4% to 6 % annually over the next five years. Purchasing Magazine Online[132] reports that a robust demand and a worldwide shortage have combined to push the prices of phenol to their highest levels in several years with further hikes likely at least through 2006. Current prices for phenol are $0.68-0.70 per lb. Improved market conditions are the result of increased crude oil prices, decreased petroleum refinery capacities, and a strong housing market. An already strong housing market is now stronger in the wake of several recent natural disasters, including the hurricanes in the U.S. and the Asian tsunami.

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[127] Kreibich (i) *Evaluation of five different lignin samples from the University of Waterloo, Ontario,* Contracted Report, Jan. 1990, (ii) *Evaluation of lignin samples from the University of Waterloo*, Contracted Report, Feb. 1991
[128] Ensyn
[129] http:/www.the-innovation-group/ChemProfiles/Phenol.htm
[130] http:/ www. purchasing.com/index.asp?layout=articleprint&articleID=ca446767
[131] http:/ www. purchasing.com/index.asp?layout=articleprint&articleID=ca508495
[132] Ibid

A 100 ton/day bio-oil refinery would produce 16-20 tons of PL per day or 5,280 -6,600 tons annually. At 68 ¢/lb this would represent a potential revenue stream of $7.1 – 8.9 million annually. Assuming a market for unfractionated PL could be established in the wood products industry this could provide the economic incentive to construct a stand alone bio-refinery facility in New Hampshire. However, there is less risk in co-locating the bio-refinery with an OSB / plywood facility in which the pyrolytic lignin is consumed as an integral component of the overall operation.

6.4 Char

In the fast pyrolysis of biomass, char is produced in quantities up to 20% by weight of the dry feedstock. The heat content of the char is approximately 14,000 Btu/lb depending upon the completeness of the pyrolysis. As shown in Figure 13 the pyrolysis process initially requires heat (endothermic) to begin the process, however at approximately 280C the process becomes exothermic (i.e., one producing heat) requiring no additional external heat. Above approximately 500C the process becomes endothermic again requiring additional heat to vaporize the remaining organic material. Above 500C the larger molecular weight organic molecules are cracked (i.e., broken into smaller molecules) causing the formation of more gaseous products and less liquid bio-oil. In a well controlled process the temperature is maintained somewhat below 500C to maximize the production of liquid bio-oil. The char produced in the low temperature pyrolysis contains 15-40 wt% organic material, thus accounting for its heat content.

In most pyrolysis operations a portion of the char is used as a fuel to dry the biomass feedstock. For green whole-tree chips as much as 30% of the char will be used in the drying process. The most obvious market for the remaining char is as a fuel. In the form of briquettes it can be sold as “charcoal” for backyard grilling.

The char is also a good soil conditioner and fertilizer. The benefits of adding char to the soil include increases in the cation exchange capacity, available water holding capacity, biomass growth, nitrogen uptake by plants, and reduced chemical runoff.

A higher value added product is activated carbon. This is formed by subjecting the hot char to superheated steam. Activated carbon can be used as a filtering material for liquids and gases. It has also been found to be useful in removing mercury from the flue gas stream of a fossil fuel combustor.

The char produced below 500C retains carboxylic acid groups, which bind ammonia exceptionally well. Char treated with ammonia to form a hydrated ammonia charcoal has been found to be a good scrubbing agent for removing SO_x and NO_x from fossil fuel combustion streams as well as reducing CO_2 emissions. The resulting products are ammonium bicarbonate, ammonium sulfate and ammonium nitrate which are excellent fertilizers.

Although all of the products from char as listed above are commercially established, no known markets have been established for products derived from char produced in a bio-oil facility. It is not known if any suppliers of bio-oil technology are actively pursuing a market for char and/or is by-products. This is considered unlikely, since existing plant configurations utilize the char for drying the feedstock and/or process heat.

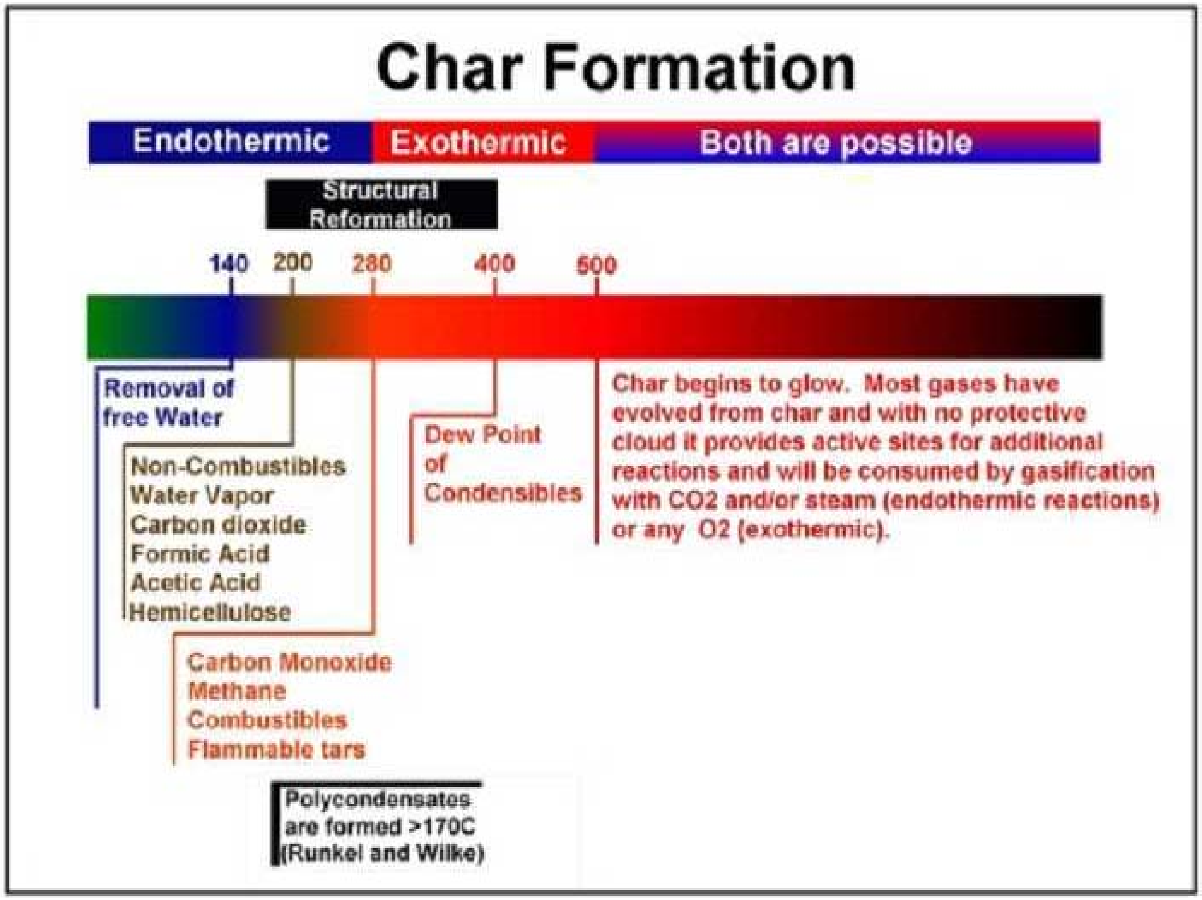

Figure 13. Thermal Properties of Char Formation [133]

6.5 Pyrolysis Gas

One hundred percent of the pyrolysis gas produced is used for process heat and therefore not considered a marketable product. As discussed earlier in this report, the use of pyrolysis gas as a synthesis gas to produce higher value products would require extensive reforming and therefore it is unlikely that it would be economically feasible to use the pyrolysis gas as a synthesis gas.

[133] Day, Danny. *Profits Options From BioFuels, Co-Products and Carbon Cycling Utilization".* Presented at Bioenergy: Status, Trends and Future of the South's Forest and Agricultural Biomass Conference, Athens, GA. August 2005.

7. Financial Analysis

In this section several plant configurations will be evaluated from an economic perspective. The economic model will be that used in a previous study with inputs modified to reflect changing economic parameters.[134] A true economic analysis should consider the full life cycle of the biomass plant with initial capital cost amortized over the entire life of the facility, typically 20 years. This is necessary in order to make a true comparison with a fossil fuel facility because the initial cost of a biomass plant can be substantially greater (50 to 200%) than a conventional fossil fuel system. The model used in this analysis considers only the first 15 years of operation, i.e., the assumed length of the capital equipment loan. This is deemed a reasonable approach for this study since most equity investors require an exit strategy with a time frame much shorter than the overall life of a plant, thus reflecting the true economic impact on such investors.

7.1 Stand-Alone Bio-oil Plant

The following financial analysis is for a stand-alone bio-oil plant. That is, the plant is not affiliated with any other commercial operation and the only revenue stream is from the sale of bio-oil and char. Process heat required for pyrolysis and drying of the green whole tree chips is provided by consuming 100% of the bio-gas and a fraction of the char and bio-oil produced. The remaining bio-oil and char will be sold on the open market. The market value of bio-oil is based on the heat equivalent of No.2 oil which is 0.54 (75,500 Btu/gal / 138,500 Btu/gal). The average wholesale market price for No.2 oil in New England for June, 2005, was $1.69 /gal.[135,136,137] Therefore, the equivalent market price for bio-oil is considered to be $0.91 /gal. The market price for char is assumed to be equal to the current market price of charcoal ($47 /ton), the lowest value added product from char

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7.1.1 Cost of Capital

The largest commercial plant currently in operation is a 45 tpd (plant size is based on dry tons). Ensyn has a 100 tpd facility under construction while DynaMotive is in the process of commissioning a 110-tpd plant.[138] Consensus is that any plant over 200- tpd would be modular in design (i.e. multiples of smaller pyrolysis units operating in parallel). For this study a 100-tpd plant will be considered. DynaMotive has estimated facility costs of $2.6MM, $5.6MM, $8.2MM and $12.6MM for 25,100, 200 and 400-tpd plants respectfully.[139] Ensyn has estimated capital costs for a 45-dry tpd plant to be approximately $2.5MM. Assuming reasonable cost for site preparation, construction

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[134] Cole Hill Associates 2004.
[135] U.S. Energy Information Administration. June 2005.
[136] EIA's Non-Transportation Fuel Sales for New Hampshire. available at www.eia.doe.gov/emu/states/oilsales_other/oilsales_othernh.html
[137] All monetary values used in this report are expressed in US$.
[138] Unless stated otherwise, all plant sizes will be based on dry tons of wood chips consumed per day (tpd). All weights expressed in tons will be short tons (2000 lbs) unless expressly stated as tonne.
[139] DynaMotive Energy Systems Corporation 2002.

cost, etc., it is estimated that the overall cost for an Ensyn facility would be approximately the same as for DynaMotive. ROI has estimated capital costs for a 120-tpd plant to be $1.2MM.[140] The reduced capital cost for an ROI installation reflects the difference in technology, i.e. use of the indirectly heated auger design.

For this study the commercially proven fluidized bed design utilized by DynaMotive and Ensyn with an estimated facility cost of $5.6MM will be used. Assuming 20% equity investment and borrowing of $4.48MM over a period of 15 years at an average interest rate of 7%, the annual debt payment (principal and interest) will be approximately $500,000. To attract equity investor(s), it is assumed that a bio-oil plant would need to generate a minimum 20% return on investment (ROI) for an additional $220,000 in cost of money annually. For a 100-tpd plant, the total cost of money (principal and interest plus ROI for the equity investors) would be approximately $720,000 annually or 19% of the annual operating cost of the facility.

In addition to capital and construction cost, an additional $1.6MM will be needed to operate the plant during commissioning along with working capital needs of approximately $700,000. Therefore, the total capital requirement for bringing a stand-alone bio-oil facility on line is estimated to be $7.8MM. These requirements are summarized in Table 11.

Utilization	Capital Cost
Capital Equipment	$ 2,500,000
Construction / Installation Cost	$ 3,100,000
Commissioning @ 6 mths	$ 1,500,000
Working Capital	$ 700,000
Total Capital Needs	$ 7,800,000

Table 11. Capital Utilization

A 100-tpd plant is expected to produce approximately 70 tons of bio-oil, 20 tons of char and 10 tons of non-condensable gases per day. One ton of bio-oil (density 1.2 kg/l or 10.04 lbs/gal) represents approximately 200 gallons of bio-oil or approximately 4.4 million gallons of bio-oil per year from a 100-tpd plant. This is equivalent to approximately 2.37 million gallons (56,000 barrels) of No.2 heating oil per year.

7.1.2 Source of Capital

Capital for the project is expected come from a combination of sources including, but not limited to, equity investment, government backed loans, commercial bank loans, line of

[140] Renewable Oil International 2002.

credit and sale of product. Equity investment would come from technology providers and private investors. Monies for the creation of new jobs are available from New Hampshire's Job Grants program administered by DRED and the Community Development Block Grant Program (CDBG), which is a loan of $20K/employee. Local economic development groups such as the Business and Economic Development Corporation (BEDCO) working in conjunction with commercial lenders can provide both money and government backed loan guarantees for capital equipment, construction, site preparation, and etc. Working capital can be obtained by a line of credit from a commercial lender secured by receivables and inventory. Table 12 summarizes possible sources of capital.

Money from grant programs administered by various federal agencies such as the U.S Department of Energy can be sought. These sources of financing tend to be time-consuming in preparation, slow to release funds, and in general very unpredictable. These sources have not been considered as a serious source of money for this project.

7.1.3 Operating Cost

7.1.3.1 Cost of Feedstock

Composition and moisture content of the feedstock affects both operating cost and product distribution, thus directly affecting profitability. Composition of the feedstock can vary from whole tree chips consisting of a blend of bark and white wood (60% white wood and 40% bark) to whole white wood chips. Product distribution

Source of Funds	Stand-Alone Plant
1. Equity Investment	
a. Investors Equity	$ 1,100,000
b. CDBG Loan for 16 employees @ $20K per employee	320,000
2. Sale of Product generated during commissioning	280,000
3. Bank Financing	
a. Capital Equipment Loan	2,500,000
b. Construction Loan	3,100,000
c. Draw on Line of Credit @ 80% Receivables, 20% Inventory	500,000
Total Funds Available	$ 7,800,000

Table 12. Source of Capital

will vary from 66% bio-oil, 21% char and 13% gas for a blend of white wood and bark, to 72% bio-oil, 15% char and 13% gas for white wood chips. Moisture content for a 60/40 blend of chips is approximately 44% as compared to 38% for whole green tree chips.[141] Thus a 60/40 blend would require an additional 8,000 tons per year of chips plus the increased cost to remove an additional 6% of moisture. The current price for whole green tree chips on the open market in Northern New Hampshire is between $24 and $30 per ton. It is assumed that a long-term contract could be negotiated for $24 to $26 per ton. For this study it is assumed that whole tree chips will be available at an average price of $26 per ton. At $26 per ton, feedstock would be the greatest cost factor representing 29% annually.

7.1.3.2 Cost of Consumables

Based on a plant configuration as described above, it is estimated that 7,750,000 kWh of electricity will be consumed annually. At a cost of 10.97 cents per kWh the cost of electricity would represent approximately 13% of the annual operating cost. Electricity costs are based on the current Public Service of New Hampshire (PSNH) rate structure as presented in Table 13. Other consumables include maintenance cost estimated at 5% of capital cost and miscellaneous consumables (i.e. water, sand, etc.) at 5% of sales.

Total Use	Monthly 645,833 kWh	Annual 7,750,000 kWh
Monthly Charges		
Energy	$ 46,758	
Consumer Charge	355	
Systems Benefit	1,938	
Electricity Consumption Tax	355	
Off-peak	8,457	
On-peak – first 150 kWh	6	
On-peak – all other	5,329	
Distribution Demand Charge	4,168	
Transmission Demand Charge	1,393	
Standard Cost Recovery	2,184	
Total	$ 70,853	$ 850,239
Cost per kWh		$ 0.1097

Table 13. Electric Use for a Bio-oil Facility Using PSNH Rate Structure

[141] Moisture content will vary based on various factors including type of wood, location, harvest season, length of storage, etc. For this report it is assumed that the average moisture content for whole wood chips at time of consumption is 44%. The chips will be dried to 8% moisture content, thus removing approximately 80% of the moisture. The moisture content will vary based on local conditions.

7.1.3.3 Cost of Labor and Labor Overhead

It is assumed that the plant will operate 24 hours a day, seven days a week with 8-hour shifts. The plant will be operational 90% of the time or 330 days/year. This will require 16 full-time hourly employees at an average annual salary of $31,200 for plant operations. In addition, general and administrative (G&A) will require one salaried manager, $62,500 annually, and 1.5 full-time equivalent hourly staff at $31,200 annually. A labor overhead rate of 23% is assumed. Outside support (i.e. legal and audit) are estimated at 75% of the in-house G&A expense. Initially, there will be no sales position. Sales will be handled by management and the equity partners (i.e. technology providers). Labor and labor overhead cost will represent 20% of the annual operating expense.

7.1.3.4 Other Cost

It is assumed that process heat for pyrolysis will be supplied by using 100% of the bio-gas plus 6% of the bio-oil produced. Char will be used to dry the green wood chips. This process will consume 31% of the char produced. A 3% license and/or royalty fee has been applied. A property tax of 0.03 mil has been used in the calculations. Other assumptions used in the pro forma calculations that are not covered above are given in Table 13.

7.1.4 Pro Forma Income Statement for a Stand-Alone Bio-oil Facility

Based on projected operating cost as outlined above, a stand-alone bio-oil plant selling bio-oil into the residential heating oil market on an energy-equivalent basis ($0.91 /gal.) would not be economically profitable (Table 15). Annual revenue losses would be approximately $100,000 annually. For the plant to break even, bio-oil must sell for $0.93 /gal and to provide a suitable return on investment for investors the sale price would need to be $0.99 /gal. Thus a premium of 2 – 8 cents/gal would be required. Even if customers were willing to pay the premium, presumably for environmental reasons, it is doubtful that a near-term residential market would develop for reasons as discussed in section 6.1.

A more likely market would be commercial/industrial customers using No.2 diesel fuel in stationary applications. Demonstration studies have shown that bio-oil can be used to replace diesel fuel for large, stationary engines. On an energy equivalent basis bio-oil selling at $0.97 /gal would show a profit of approximately $150,000 annually. Thus, having a breakeven price of $0.94 /gal and a suitable return on investment for investors at $0.99 /gal., this could represent a suitable market.

Commercial/industrial users of No.6 fuel oil would not be an attractive market. Selling at an energy equivalent price of No.6 fuel oil, a bio-oil plant would sustain losses of approximately $1.5MM annually. To be competitive in this market would require an incentive (i.e. subsidy) of approximately $0.49 /gal. Although not unreasonable considering current ethanol subsidies, there is no consideration for such subsidies at this time. These results are consistent with conclusions drawn in section 6.1; market analysis based on bio-oil as a heating oil and current market price for various oil fractions.

Item	Amount
Plant Size	100-tpd
Plant Availability	90%, 330 days/yr
Raw Feedstock Consumed	45,540 green t/yr
Feedstock Cost	$ 26 /green ton
Feedstock Composition	Whole tree chips
Moisture Content	45%
Bio-oil Yield	66%
Bio-oil Production	4,356,000 gal/yr
Bio-oil Yield per ton	132 gal/t bio-oil
Bio-oil Heat Content	75,500 btu/gal
Wholesale Cost of No.2 Fuel Oil	$ 1.69 gal
Density Bio-oil	1.2 kg/l – 10.04 lbs/gal
Char Yield	21%
Char Production	6,930 t/yr
Plant Capital Cost	$ 5.6MM
Equity	20%
Capital Debt Financed	$ 4.48MM
Bank Financing - Line of Credit	$ 1.6MM
Return on Investment (ROI)	20%
Debt Amortization	15 yr
Finance Rate	7%
Electricity Consumed	7,750,000 kWh
Cost of Electricity	$ 0.1097 /kWh
Labor Rate (Hourly)	$ 31,200 /yr
Labor Rate (Salaried)	$ 62.,500 /yr
Production Staff	16
G&A Staff	1 (Salaried) 1.5 fte (hourly)
Professional Services	75% of G&A Staff Cost
Overhead Rate	23%
Process Heat	Bio-gas and Bio-oil for pyrolysis heat; Char for dryer heat
Bio-oil Consumed	6%
Char Consumed	31%
Maintenance Cost (% Capital)	5%
Consumables (% Sales)	5%
Royalty / License Fee (% Sales)	3%

Table 14. Assumptions and Conversion Factors Used in Calculations

Stand-Alone Bio-oil Plant			
Net Sales			
Bio-oil	$ 3,951,948		
Char	213,231		
Electricity	-		
Chemicals	-		
Total Sales		$ 4,165,179	
Cost of Goods Sold			
Labor & Overhead	614,016		14%
Feedstock	1,184,040		28%
Electricity	850,175		20%
Consumables	208,259		5%
Maintenance	280,000		7%
Total COGS		3,136,490	
Gross Profit / (Loss)		1,028,690	
Operating Expenses			
SG&A	235,268		6%
Cost of Money	603,880		14%
Royalty	124,955		3%
Property Tax	168,000		4%
Total Operating Expense		1,132,104	
Net Profit / (Loss)		$ (103,414)	
Break Even Bio-oil Price	$ 0.93	/gal	
Break Even Electricity Price	-	/kWh	
Break Even Chemical Price	-	/lb	
20% ROI Bio-oil Price	$ 0.99	/gal	
==			
Assumptions			
Feedstock Price	$ 26.00	/ton	
Bio-oil Sales Price	0.91	/gal	
Price of No.2 Fuel Oil	1.69	/gal	
Char Sales Price	47.00	/gal	
Electricity Sales Price	-	/kWh	
Chemicals Sales Price	-	/lb	

Table 15. Pro Forma Income Statement for a Stand-Alone Bio-oil Plant

Although complete replacement of No.6 oil by bio-oil may not be economically viable, co-firing with No.6 and other fossil fuels could be. For high sulfur fossil fuels, co-firing would substantially reduce atmospheric pollutants reducing the need for costly emission stream cleanup. Thus co-firing in plants using high sulfur fossil fuels could be a market option.

The largest cost for a bio-oil plant is feedstock, which represents 29% of the operating expense. It has generally been assumed that as the price of oil increased, bio-oil would become more economically viable. However, as shown in Figure 14, as the price of oil increased so did the price of whole tree chips. This is understandable since the harvesting of whole tree chips is energy intensive, both in the chipping process and transportation.

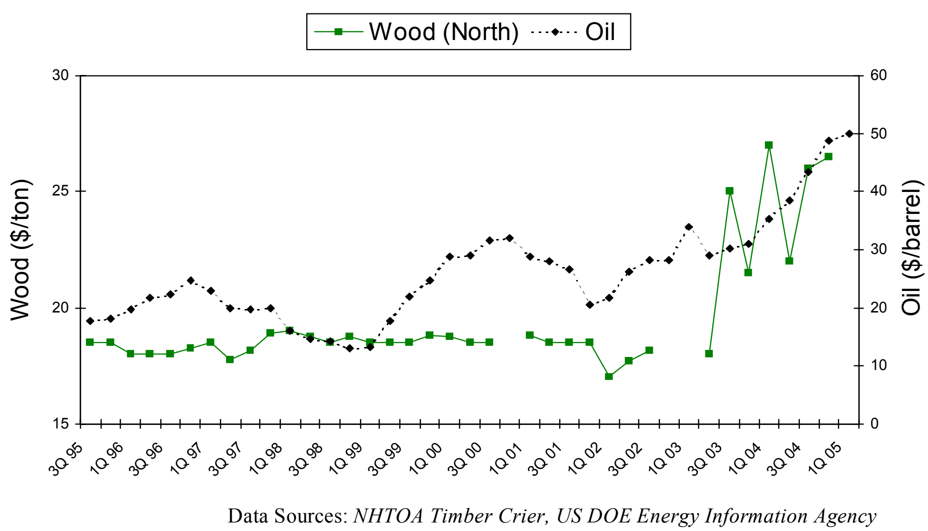

Figure 14. Price Comparison of Wood Chip vs. Crude Oil

For bio-oil to compete with petroleum based products one or more of the following must happen:

1. the cost of feedstock must decline,
2. the cost of oil must increase significantly,
3. state and/or federal governments must provide a market incentive similar to that currently in place for ethanol, and/or
4. additional value-added products must be extracted and successfully marketed.

Relying on declining feedstock prices at increasing oil prices is unreasonable given the apparent relationship between the price of feedstock and oil. This eliminates options 1 and 2. At present there is no movement for governments to provide an adequate subsidy program. To be effective a subsidy on the order of 49 cents/gal would be required for bio-oil to be competitive in the commercial/industrial market. A near-term residential market is not reasonable as discussed in section 6.1; however, it is possible to be competitive in the commercial/industrial sector currently using diesel fuel. Realistically, the most viable option is a bio-refinery in which higher value added chemicals are extracted for sale along with the residual bio-oil.

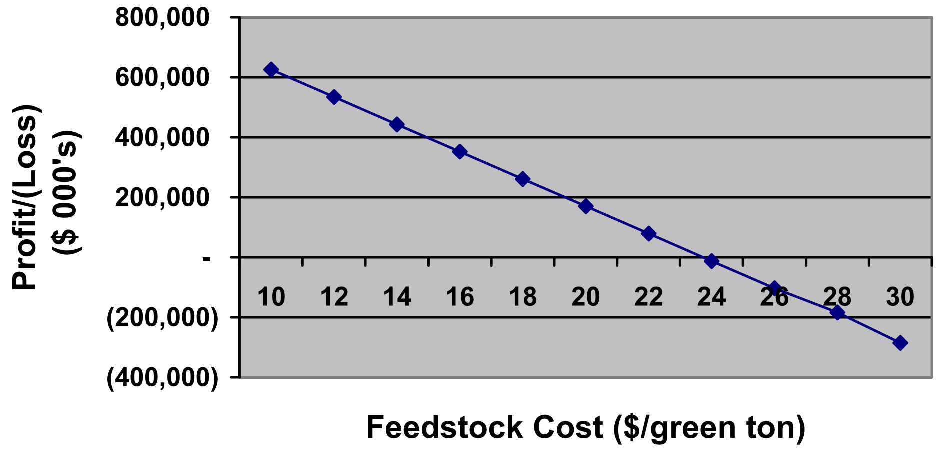

Figure 15. Stand-Alone Bio-oil Profit/(Loss) vs. Feedstock Cost

7.2 Combined Bio-oil / Electric Power Generation Plant

A bio-oil facility operating in New Hampshire would have the opportunity to sell electricity in the ISO-New England (ISO-NE) market serving the six New England States. To sell electricity at the wholesale level, the plant would need to interconnect with the electricity transmission and distribution system, the “grid”, and have a means for generating electricity. DynaMotive Energy Systems Corporation (DynaMotive) is currently in the process of commissioning such a plant in Ontario, Canada. DynaMotive will utilize fifty tons of bio-oil per day (70% of the production of a 100 ton/day plant) to fuel a gas turbine developed by Orenda to produce up to 2.5 MW of electricity, enough to serve 2,500 households. A plant producing 2.5 -3 MW would be considered a small scale operation. The capital cost to include a direct-fired gas turbine and equipment necessary to connect to the grid would cost approximately $3MM. Thus the total capital cost for this configuration would be $8.6MM with an additional up-front requirement of $600,000 in equity and $265,000 in cost of money annually. A less costly option would be to use a more conventional boiler/steam turbine configuration. Capital equipment cost are estimated to be 30-50% lower than that of the gas turbine.

A stand-alone plant will not be able to take advantage of increased efficiencies gained by operating in either a combined cycle mode or as a co-generation plant. The plant will produce its own electric power, thus reducing the cost of electricity. The cost of electricity will be calculated using grid clearing prices. Even assuming the plant can sell into the RPS market with credits of 4-4.5 cents /kWh, the initial capital cost along with operating cost of feedstock make this plant too costly to operate profitably. The economic model shows such a plant operating at a loss of $1MM to $1.5MM annually depending upon the electric power generating configuration used. For the less capital-intensive boiler/steam turbine configuration the plant would need to sell at grid clearing prices of approximately $100 /MWh (3-4 times current grid clearing prices) to be profitable. Such a plant is capital intensive and too small to be economically viable using any reasonable economic model.

An alternative scenario would be a bio-oil, electric power generating plant either co-located with or located near a forest products manufacturing plant site. In this scenario the bio-oil plant will buy plant residues for fuel to generate electricity and sell this electricity back to the manufacturing facility with any excess being sold on the grid. This arrangement provides a market for wood residue while providing a source of electric power and processing heat for the forest products plant without the forest products plant having to finance the cost of the generating facility. Ideal sites for co-locating a plant would be near sawmills, kilns, fiberboard mills, OSB plants, and veneer mills. This is the configuration being utilized by plants currently under construction by DynaMotive in Ontario where the plant is locating near the Erie Flooring plant, by Ensyn in Renfrew, Ontario, where the plant is located near a sawmill and kiln operation, and by ROI in Chesterfield, Massachusetts where the plant will be co-located with Berkshire Hardwoods.

A 100-ton /day facility will produce 2.5-3 MW of electric power, 2,600 gallons of bio-oil, and 14 tons of char a day along with enough surplus heat from the turbine to produce 12,000 pounds of steam per hour. Electric power can be used to meet the needs of the forest products plant with the excess exported to the energy grid. Bio-oil and char can be used to fuel existing boilers and/or be sold to other commercial users. Surplus heat can be used for industrial operations (cogeneration). For this type of operation it is difficult to provide an economic evaluation since the economics depend upon agreements between the parties involved. It is assumed that the feedstock, electric power and process heat are provided at prices mutually beneficial to all parties. This seems to be an economically viable operating scenario.

Unfortunately this operating structure is not applicable to New Hampshire. In reviewing currently operating forest products plants in the state, it was found that there are no plants large enough to support such a facility, either by producing adequate feedstock and/or utilizing a significant portion of the electric power or process heat that would be produced.[142] It is deemed unlikely that the state would be able to attract such forest product plants in the foreseeable future.

A second alternative would be to co-locate a bio-oil /electric power generating facility with an existing wood-fired power plant. There are currently three wood-fired plants operating in the vicinity of Whitefield, NH, two of which will lose their rate orders within the next 1-2 years. The third is Whitefield Power and Light, which is not operating under a rate order, but has rebuilt its boiler to meet Connecticut RPS requirements. This would allow the plants to cost share by:

a. using common facilities such as wood handling facilities and office space,
b. reducing operating expenses through sharing labor, labor overhead, and G&A resources,
c. using existing facilities for connecting to the grid,
d. utilizing waste heat from the wood fired plant to dry wood for the bio-oil plant,
e. operating in a combined-cycle mode where heat recovered from the gas – turbine exhaust can be used to generate power and heat in the existing steam turbine, thus reducing the amount of feedstock required by the wood-fired plant, and
f. co-firing the wood boiler with the excess bio-oil and char, further reducing the cost of wood chips.

Using the above scenario, there would be savings for both the wood-fired plant and the bio-oil plant. Without knowing the exact business relationship that could be negotiated between the parties, it is impossible to predict the economic impact on either party independently. However, if it is assumed that both parties enter into an equal partnership such that the savings are shared equally, the following conclusions can be made:

a. By sharing existing wood handling facilities and grid connection, capital equipment needs can be reduced by an estimated $1.8MM, thus reducing the cost of money by approximately $130,000 annually.
b. Labor, labor overhead and G&A savings would be approximately $365,000 annually.
c. Using waste heat to dry the wood chips, co-firing the boiler with excess bio-oil and char, and using the exhaust gas from the gas turbine, would reduce feedstock consumption of the power plant by approximately 25,000 tons or $650,000 annually.

With these savings the bio-oil portion of the facility would be operating at a breakeven to small profit. Therefore the combined facility would generate an overall profit equal to that of the original wood-fired plant. While beneficial to the owners of the bio-oil plant, there would be no benefit for and, therefore, no incentive for the owner of the wood-fired plant to enter into such an arrangement. Plants that are about to lose their rate order, and

[142] University of New Hampshire, Cooperative Extension. *New Hampshire Directory of Sawmills & Lumber Wholesalers.* Contact Sarah Smith, UNH Cooperative Extension. (603) 862-2647.

therefore would not be able to operate profitably as currently structured, may find this an attractive alternative if the new plant could meet RPS requirements and sell RPS credits.

7.3 Bio-refinery

The third and final option to be considered is a bio-refinery. A bio-refinery includes the features of a bio-oil production plant and an electric generating plant plus the added ability to extract a variety of chemicals which when sold on the open market increase the overall revenue stream of the plant. The bio-oil remaining after chemical extraction is used for either space and/or process heat or to generate electric power. An example of such a plant is an Ensyn designed bio-refinery operated by Red Arrow in which food flavorings are extracted from the bio-oil and the residual bio-oil is used to generate process heat for the Red Arrow plant. Ensyn is currently constructing a new bio-refinery in Renfrew, Ontario. This plant will use wood waste from nearby sawmills as a feedstock, produce electric power using a conventional boiler/steam turbine configuration, provide process heat to a nearby kiln operation, and extract a phenolic resin which will be used in the fiberboard industry.

Ensyn has worked with Louisiana Pacific, Weyerhaeuser and Tembec, integrated forest products companies and Dynea, Georgia Pacific and Tembec, North American resin producers to demonstrate and develop a commercial process using waste bark to produce wood adhesives.[143] The phenol-formaldehyde (PF) resin was produced using Ensyn's commercial RTP™ process. These phenol substitutes are identified as Natural Resin (NR) which is a "green" or "eco" resin known commercially as NMRP. These natural resins produced from biomass can replace up to 50% of the petroleum-based phenols currently used in the production of OSB and other fiberboard products. These "natural resins" are produced as solid flakes or powders, which are easily handled and shipped to resin producers.

The basic pyrolysis operation in a bio-refinery is the same as discussed for a stand-alone bio-oil plant. In addition, one must add the necessary equipment for chemical extraction. The actual extraction process and equipment configuration is proprietary; however, from discussions with Ensyn management it is estimated that capital equipment cost would be approximately \$1MM with a total installation cost of approximately \$2MM. Using a boiler/steam turbine for electric power production, the total estimated cost of a stand-alone bio-refinery would be \$11,550,000. The use of capital for a bio-refinery as compared to that for a stand-alone bio-oil plant is shown in Figure 16.

The extraction of MNRP would result in a 25% reduction in bio-oil production. This is consistent with analysis showing that typically 24-28% of the bio-oil recovered is a so-called pyrolytic lignin (PL) fraction. For a 100–tpd plant this represents a production of approximately 10.5 million pounds of MNRP (pyrolytic lignin) annually. Pyrolytic lignin replaces phenol, a petroleum based chemical, in the production of phenol-formaldehyde resins. The current market price for phenol is at an all-time high of \$0.68 /lb with an

[143] Graham, Robert G. 2003.

average price over the past ten years of $0.35 /lb. Since PL is an unrefined replacement for phenol with no market history and/or performance history a market price of $0.35 /lb will be assumed for this study. This is equal to the historical average market price for phenol over the past ten years. The market value of char used in this study will be that of higher value added products as discussed in Section 6.4 which is estimated to be $109 per ton. Using the above information along with previously discussed economic parameters, a stand-alone bio-refinery is expected to show a profit of approximately $1.8MM annually assuming bio-oil is sold for $0.91 /gal and chemicals for and average of $0.35 /lb.

Utilization	Stand-Alone	Bio-Refinery
Capital Equipment	$ 2,500,000	$ 4,500,000
Construction / Instillation Cost	3,100,000	4,100,000
Commissioning @ 6 mths	1,500,000	2,100,000
Working Capital	700,000	850,000
Total Capital Needs	$ 7,800,000	$11,550,000

Table 16. Capital Cost: Stand-Alone Bio-oil Plant vs. Bio-refinery

A 20% ROI for investors can be maintained if the chemicals are sold for $0.20 /lb.

A bio-refinery co-located with a wood-fired power plant and using the assumptions from the previous section show a net profit of approximately $1.7MM annually with a 20% ROI sales price of $0.22 /lb for chemicals after the sale of RPS credits. Co-locating with an existing wood-fired power plant should be economically attractive; however, co-locating with a forest products plant which would be a source of low cost feedstock as well as a consumer of products from the bio-refinery would be an even better choice.

Consequently, the suppliers of bio-refinery technology are focusing their available resources on developing business partnerships with forest products plants. Since appropriate forest products plants are not available in New Hampshire, there is no reason for a bio-refinery to consider locating in New Hampshire without suitable incentives. Such incentives would include financial support by local and state government to reduce the cost of money for capital equipment and construction costs. Such support is currently available from several southeastern states, which have ample supplies of feedstock and active forest products industries. Without similar support it is unlikely that New Hampshire will be able to attract a bio-refinery.

8. Bio-Refinery Technology Beyond Bio-oil

Although not apart of this study, it would be inappropriate to conclude without a brief statement concerning the broader overall scope of a bio-refinery beyond that of simply bio-oil derived chemicals. For this report fast pyrolysis of biomass was carried out in an oxygen-free atmosphere to produce the liquid bio-oil. Under carefully controlled temperatures and with the addition of a small amount of oxygen (e.g. about one third the

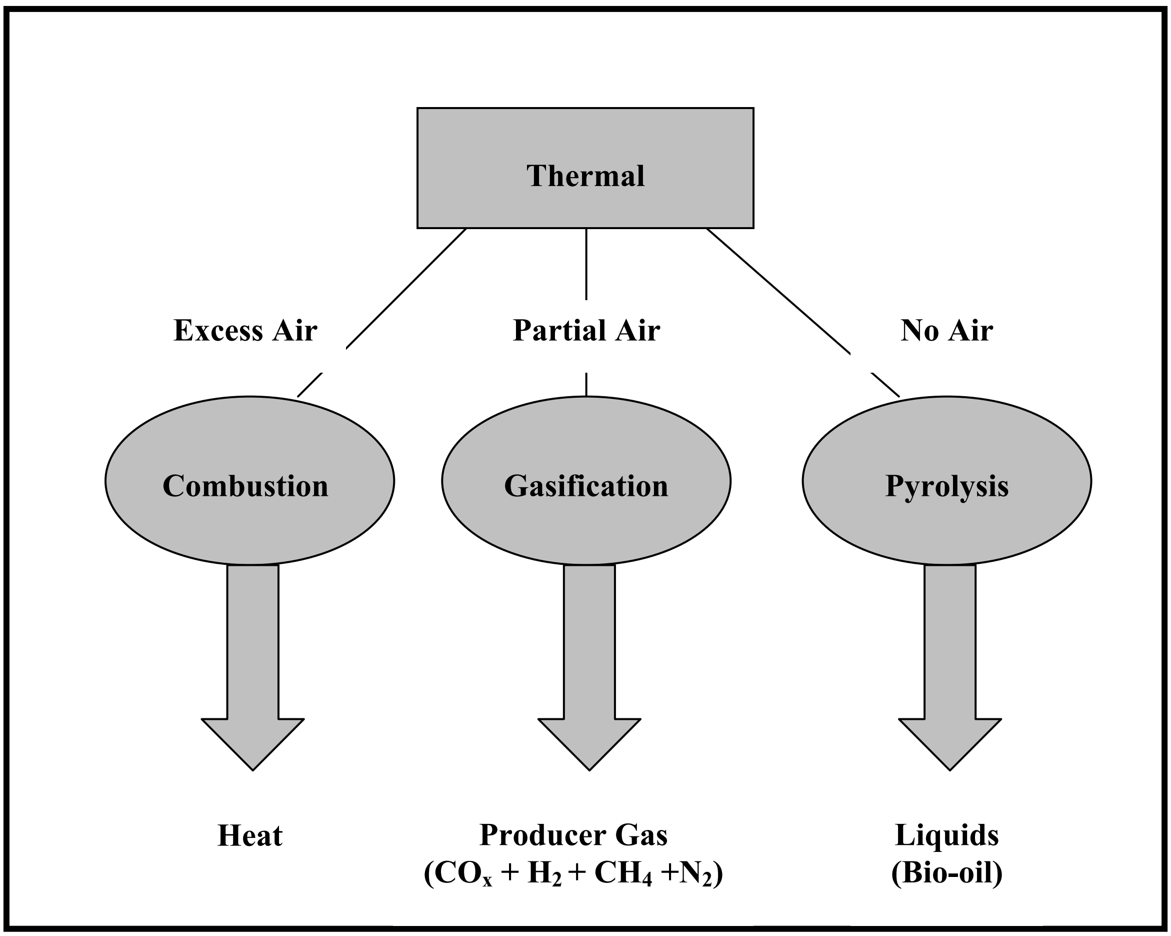

Figure 16. Biomass Conversion Pathways

amount of oxygen needed for combustion) biomass fuels can be converted into a gaseous fuel known as producer gas. Producer gas consists of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. The producer gas has a low heat content but can be burned without the emission of smoke. Like natural gas, producer gas (or syngas) can be burned in gas turbines for more efficient electrical generation than by using steam boilers as required for solid biomass fuels and fossil fuels. The combined heat and power generation via biomass using gas-fired engines or gas turbines can achieve efficiencies between 22% and 37% compared to combustion technologies using a steam turbine with efficiencies of 15% to 18%.[144] If producer gas is used in a fuel cell, efficiencies approaching 50% can be achieved. Biomass gasification is environment-friendly with no SO_x emissions, reduced NO_x emissions and is CO_2 neutral.

Rather than burning the syngas, it can be converted into a large number of organic compounds that are useful chemical feedstocks, fuels and solvents by a method known as Fischer-Tropsch (FT) synthesis. FT is a well-known commercial process being used since 1938 for the production of liquid fuels from coal and crude oil. The process uses selective catalyst under heat and pressure to convert the syngas stream.

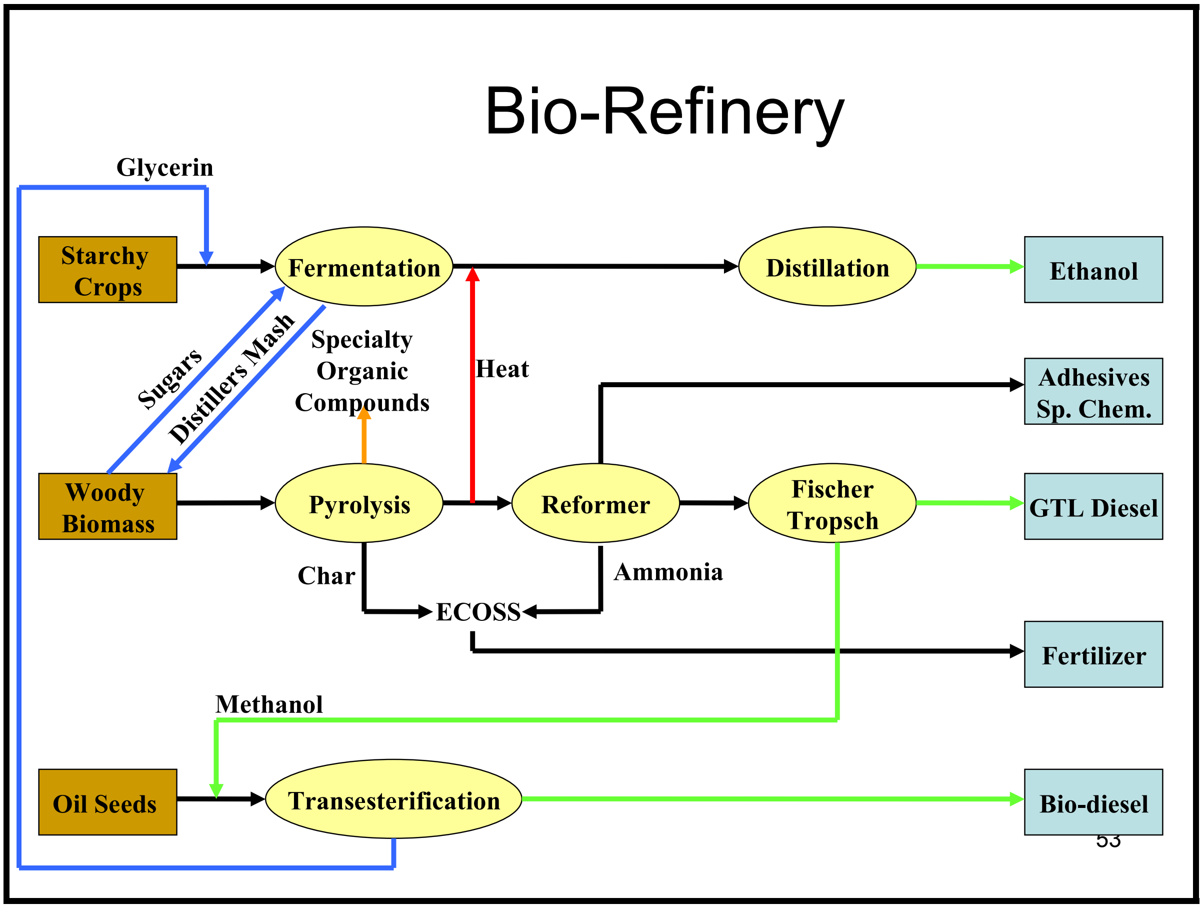

Figure 17. Bio-Refinery as Envisioned by Researchers at Warnell School of Forest Resources, University of Georgia

[144] *Gasification and pyrolysis of biomass*. http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm

Significant research in biomass gasification is being conducted by numerous groups. One such group is Eprida,[145] a private research partner with the Warnell School of Forest Resources at the University of Georgia. Figure 17 represents a bio-refinery concept as envisioned by researchers in this group.[146] This concept includes the conversion of starchy crops and grains as well as wood feedstocks. Focusing on the conversion of wood, sugars can be extracted prior to pyrolysis and fermented to form ethanol, specialty chemicals and adhesives can be extracted from pyrolysis liquids as discussed in previous sections, and syngas can be converted into hydrogen, and fertilizers with the addition of super-heated steam and nitrogen, or converted to liquid fuels using Fischer-Tropsch synthesis. Figure 18 is a schematic showing the economically more important chemicals that can be derived from the syngas generated by the pyrolysis of biomass.

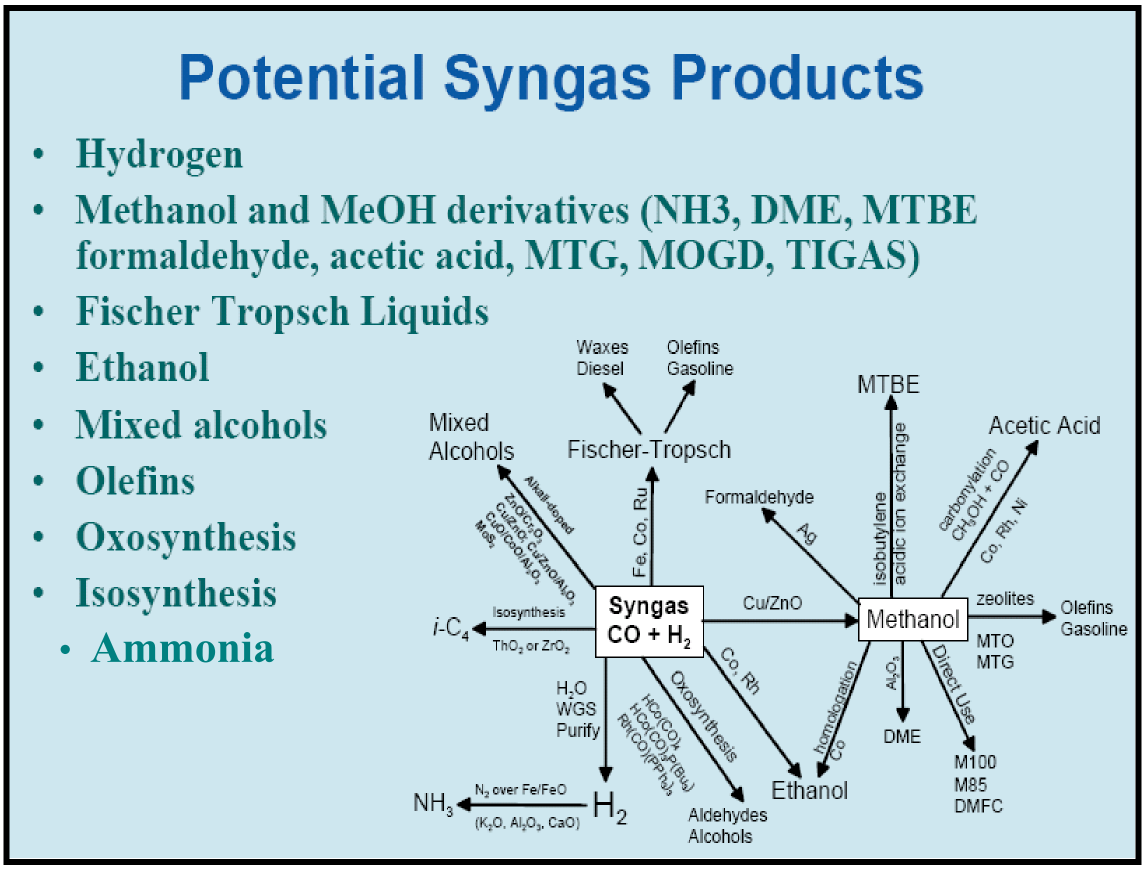

Figure 18. Potential Syngas Products [147]

[145] Eprida web page http://www.eprida.com/index.html
[146] Day 2005
[147] Ibid

A more detailed schematic of the pyrolysis portion of the bio-refinery concept is given in Figure 19. Here the focus is on production of hydrogen fuel, hydrated ammonia charcoal for scrubbing effluent gas streams from the combustion of fossil fuels, and the use of the resultant chemicals as a fertilizer.

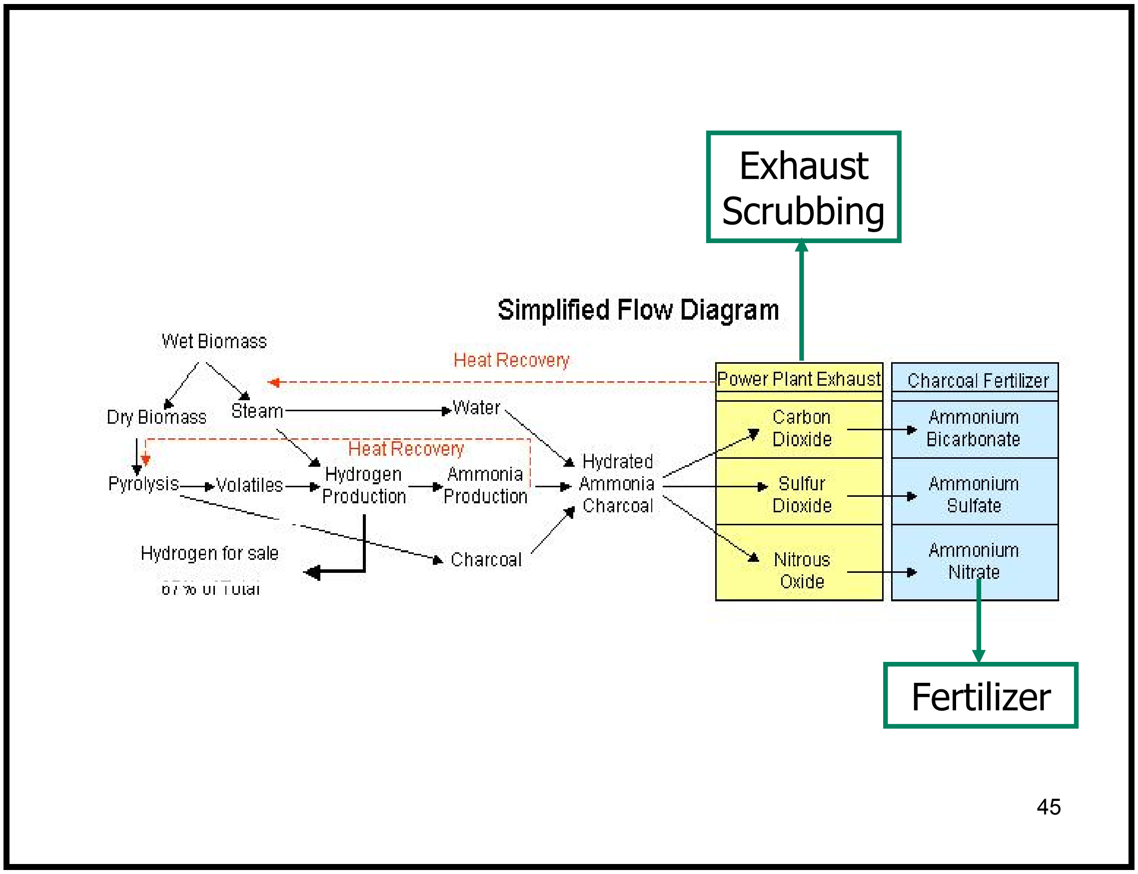

Figure 19. Bio-Refinery Concept with an Emphasis on the Pyrolysis of Biomass [148]

BioConversion Technology, LLC (BCT) is another group studying the gasification of biomass to produce clean energy. The commercial application of this technology is being promoted by Phoenix Consulting Group International, LLC ("PCGI").[149,150] BCT uses a patented pyrolytic steam reforming gasifier coupled with a staged temperature reaction process to produce a medium to high Btu, clean syngas. A schematic representation of the BCT gasifier as presented by BCT is shown in Figure 20. The syngas is reported to have an energy content in the range of 400-600 Btu/ft^3 while being ultra clean with no particulates, tar, alkali metals and low in NO_x, SO_x and CO_2. The resulting syngas can be converted into liquid fuels (e.g. ethanol, methanol), electricity,

[148] Ibid

[149] Stewart, Laurence W. *Biomass and Carbonaceous Materials to Clean Energy and Fuels.* Presented at Bioenergy: Status, Trends and Future of the South's Forest and Agricultural Biomass Conference. Athens, GA. August 2005. available at hhtp;://biomass.sref.info/proceedings. htm

[150] Phoenix Consulting Group International, LLC web site http://www.phoenixcgi.com

hydrogen, or enhanced to pipeline quality for use as a natural gas replacement. BCT reports that their gasifier has been chosen by the Department of Defense to convert waste generated by the military, has been identified as the preferred method for disposing of "forest slash" generated in an effort to thin western forests and has been identified as the preferred technology to convert agricultural waste to higher value liquid fuels by a California agricultural cooperative.

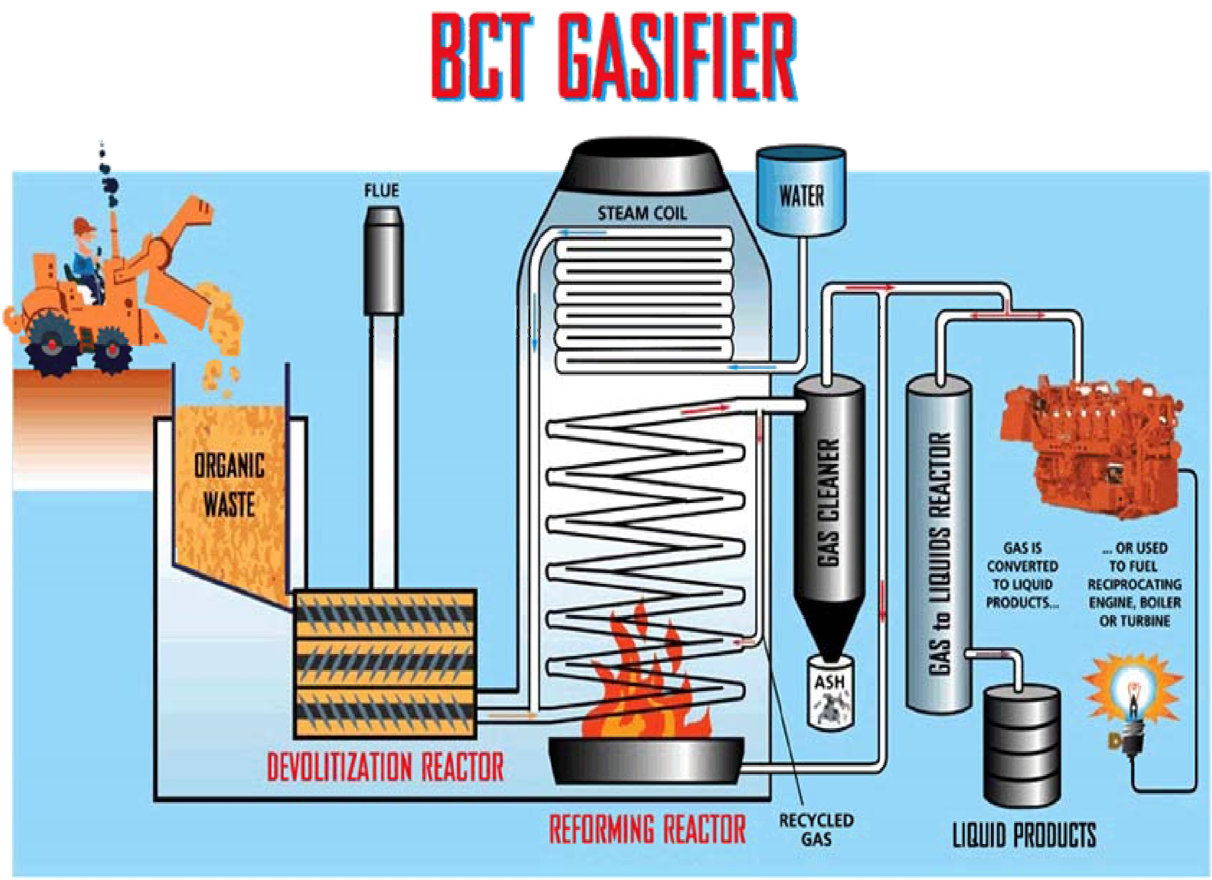

Figure 20. BCT Gasifier [151]

[151] Stewart 2005

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Biomass Research and Development Initiative
http://bioproducts-bioenergy.gov/

British Columbia Ministry of Forests
http://www.for.gov.bc.ca/hfp/pubs

DynaMotive Energy Systems Corporation
http://www.dynamotive.com]

Educational Website on Biomass and Bioenergy
http://www.aboutbioenergy.info/index.html

Ensyn Renewables, Inc.
http://www.ensyn.com

Foster's Daily Democrat
http://www.fosters.com

IEA Bioenergy
http://www.ieabioenergy.com/index.php

ISO New England
www.isone.org

National Association of Conservation Districts
http://www.forestry.nacdnet.org/biomass/WoodBiomass.htm

National Association of Conservation Districts
http://www.forestry.nacdnet.org/forestrynotes

National Resources Canada, CANMET Energy Technology Center (CETC)
www.cetc-ctec.gc.ca

New England Region US Forest Management Service Center
http://www.fs.fed.us/ne

New Hampshire Department of Resources and Economic Development
http://www.nh.gov/dred/divisions/forestandlands/reference/documents

New Hampshire Office of Energy and Planning
http://www.nh.gov/oep/programs/energy/bioOil.htm

New Hampshire Timberland Owners Association
http://www.nhtoa.org/nhforestindustry.htm

NREL Biomass
http://www.nrel.gov/biomass/

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Renewable Fuels Association
http://www.ethanolrfa.org

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http://www.unh.edu/Forestry/Forestry.htm

USDA Forest Products Lab
http://www.fpl.fs.fed.us/

USDA Forest Service – Research & Development
http://www.treesearch.fs.fed.us

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http://www.eere.energy.gov/biomass/

U.S. Energy Information Administration
http://www.eia.doe.gov

US Forest Management Service Center
http://www.fs.fed.us/fmsc/sdu/biomass/index.php

Glossary

Ash. The noncombustible components of fuel.

Biobased product. A commercial or industrial product (other than food or feed) made of renewable biological products such as forestry materials.

Bioenergy. Energy derived from organic matter, whether directly from plants or indirectly from plant-derived industrial, commercial, forestry or urban wastes.

Bioenergy crops. Fast growing crops grown to produce energy – traditionally poplar, willow, sweetgum and cottonwood. Also referred to as energy feedstocks.

Biofuels. Mostly liquid fuels for transportation produced from biomass and used instead of petroleum products. Examples include ethanol, methanol, and biodiesel.

Biogas. A gas produced from biomass, usually combustible.

Biomass. Organic matter available on a renewable basis. For our purposes, biomass can be small diameter trees and brush from forest thinning operations, wood residues, and short rotation woody crops planted to produce energy, or wood waste from demolition or other sources.

British thermal unit (Btu). A standard unit of energy equal to the heat required to increase the temperature of 1 lb (0.45 kg) of water 1^{o}F (0.56C).

Biorefinery. An integrated processing plant envisioned to "biorefine" biomass from multiple sources into chemicals, fibers, biofuels, pharmaceuticals, and other high-yield products.

Carbon cycle. The process of transporting and transforming carbon throughout the natural life cycle of a tree from the removal of CO_2 from the atmosphere to the accumulation of carbon in the tree as it grows, and the release of CO_2 back into the atmosphere when the tree naturally decays or is burned.

Carbon sequestration. Refers to the long-term storage of carbon on land (in trees and other plants), underground or in oceans.

Char. Carbon-rich combustible solids that result from pyrolysis of wood in the early stages of combustion. Char can be converted to combustible gases under certain conditions or burned directly.

Chipper. A device that reduces logs, whole trees, slab wood, or lumber to chips of more or less uniform size. Stationary chippers are used in sawmills, whole trailer-mounted whole-tree chippers are used in the woods.

Co-firing. Utilization of bioenergy feedstocks as a supplementary energy source in high efficiency boilers.

Cogeneration. Combined heat and power (CHP).

Combined heat and power (CHP). The simultaneous production of heat and mechanical work or electricity from a single fuel.

Combustion air. Air that is used for the burning of a fuel.

Combustion efficiency. The efficiency of converting available chemical energy in the fuel to heat. It6 measures only the completeness of fuel combustion that occurs in the combustion chamber.

Combustor. The primary combustion unit, usually located next to the boiler or heat exchanger.

Densified biomass fuel. Biomass material that has been dried and compressed to increase its density.

Excess air. The amount of combustion air supplied to the fire that exceeds the theoretical air requirement to give complete combustion.

Flue gas. All gases and products of combustion exhausted through the flue or chimney.

Fly ash. Ash transported through the combustion chamber by the exhaust gases and generally deposited in the boiler heat exchanger.

Gasification. The process of heating wood in an oxygen-starved chamber until the release of volatile gases that can then be combusted to produce heat and electricity.

Gasifier. A combustion device that produces biogas from solid biomass.

Kilowatt. A standard unit for expressing the rate of electrical power output.

Particulates. Minute, solid, airborne particles that result from biomass combustion.

Pyrolysis. A process of combustion at oxygen-starved conditions, involving the physical and chemical decomposition of solid organic matter by the action of heat into liquids, gases, and a carbon char residue.

Residence time. The length of time the fuel remains in the combustion zone.

Renewable energy. Any energy source that can be replenished continuously or within a moderate timeframe.

Renewable Portfolio Standard. Also called a renewable energy standard, requires that a specific percent of a utility's generating capacity or energy sales be derived from renewable energy sources such as wind, solar, landfill gas, geothermal and biomass. Some standards require that the utility reach a target percent by a certain year. Most RPS's are implemented at the State level. For more information see http://www.ucusa.org/clean-energy/renewable_energy/page.cfm?page ID=114.

Whole-tree chips. Wood chips produced in the woods by feeding whole trees or tree stems into a mobile chipper that discharges directly into a tractor-trailer.

Wood gasification. The process of heating wood in an oxygen-starved chamber until volatile pyrolysis gases (e.g.,, CO, H_2, O_2) are released from the wood. The gases emitted are low- or medium-energy-content gases that can be combusted in various ways.

Wood Residues. Wood not harvested for bioenergy purposes, such as leftovers from lumber or pulp operations.